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A water wave recording instrument for use in hydraulic models

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Abstract. Consideration is given to the requirements of a water waveform recording instrument and to the details of an instrument designed to meet these requirements. The instrument has a linear calibration, and tests show that over a wide range of conditions its accuracy is to better than 2%. A capacitance type sensing element is used, together with transistor circuits and a pen recorder. The device is suitable for recording water waves in hydraulic models.

1. Introduction

The measurement of water-wave magnitudes and the recording of waveforms is often carried out in hydraulic laboratories. If, for example, the most suitable position and length of a harbour breakwater is required, a model of the harbour is constructed, artificial waves are produced, and measurements of their magnitudes are made. Efficient instrumentation for the model is conducive to more comprehensive investigations, and these could result in a more effective breakwater. It is very convenient if the instrument sensing probes can be placed in appropriate positions throughout the model and switched to the recording instrument as required. Simultaneous recording on a number of recorders is desirable if these are available.

The requirements of any measuring instrument are: firstly, that the sensing element must not affect the entity being measured, except perhaps to a negligible degree; secondly, that the instrument output be a convenient function of the entity being measured, and if it depends on other factors, these must not vary; and thirdly, the instrument must be readily used and not unnecessarily complicated.

Electrical water-wave measuring devices have replaced mechanical systems in recent years because of their greater reliability and improved accuracy. Probes can be designed so that they do not affect the waveforms to any significant extent and so the first requirement is readily satisfied. Systems which measure the water conductivity between two probes are often used but their calibration characteristics are non-linear because of probe end effects, and they vary as water conductivity varies. It could be said, therefore, that the conductivity probe systems do not satisfy the second requirement—however, a system has been demonstrated using a polyethylene insulated wire capacitance sensing head, and its characteristics were stated to be linear and stable (Tucker and Charnock 1954). The system, as demonstrated, required high frequency vacuum tube circuits, and there was a limit to the length of coaxial cable which could be used to connect the probe to the measuring circuits. The device, although it satisfies the first two requirements, may not satisfy the third requirement mentioned above, since it has a limited range of usefulness and is perhaps too sophisticated.

The instrument described uses a capacitance-type sensing element and a simple transistor circuit incorporated in the probe unit, and this gives an output current corresponding to the depth of immersion of the sensing probe. Because the output is a low frequency signal (being water-wave frequency) very long connecting leads to the recording system may be used if required. There is a preset calibration adjustment for each probe and therefore a flexible multiprobe multirecorder system is possible. Associated with each recorder is an amplifier and a probe selection switch, and associated with each probe unit is a level setting potentiometer and a calibration adjustment potentiometer. The switches and potentiometers are incorporated in a separate unit which may be extended, if the system is expanded, to accommodate more probes or recorders. The author considers that the instrument presented in this paper satisfies the requirements listed above, not only because of its inherent

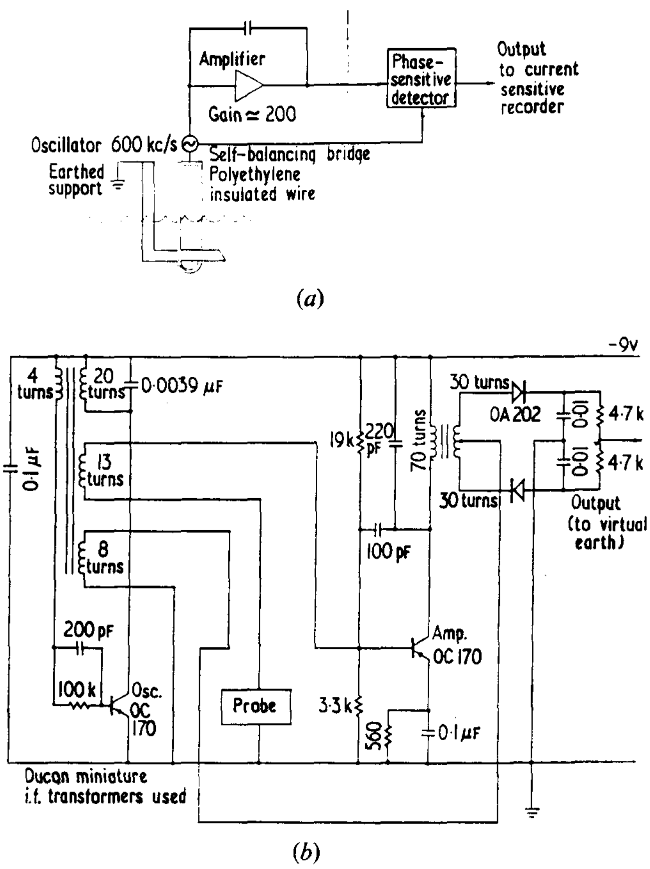

Figure 1. Probe unit details, (*a*) schematic, (*b*) circuit.

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linearity and stability, but also because it is readily constructed, it is flexible in operation and is easily used.

2. The instrument details

2.1. *The probe unit* (figure 1)

2.1.1. *The probe.* There is a linear relationship between the depth of immersion of the probe and the capacitance between the insulated wire and the water. The linearity of the relationship depends only on the uniformity of the insulation of the wire covering. At the frequency applied to the probe (600 kc/s), the water surrounding the wire can be considered as being at the same potential as the earthed support because of the high dielectric constant of water. The relevant capacitance is therefore that between the insulated wire and earth, and it is this that is proportional to the depth of probe immersion. Polyethylene insulated wire is quite suitable because it does not absorb water, and if necessary it can be coated with a silicone liquid which reduces any adhering water film to droplets. The wire used in the probe is 0·022 in. in diameter with an insulation thickness of 0·012 in.

2.1.2. *The probe unit circuitry* (figure 1(*a*)). The circuit, which is used to give changes in output current proportional to probe capacitance, is essentially a self-balancing bridge followed by a detector. The oscillator and probe capacitance of figure 1(*a*) are in series, and feed into an amplifier which is tuned to the oscillator frequency and has a feedback capacitor from its output to its input. The input impedance to the amplifier is a very large capacitance and so appears as a virtual earth to the input signal. Because of the high transfer impedance of the amplifier, practically all the current fed to the amplifier flows through its feedback capacitor. The output of the amplifier is then proportional to the oscillator amplitude and the probe capacitance, and inversely proportional to the feedback capacitance. Because the detected output is proportional to the probe capacitance it is therefore proportional to the depth of immersion of the probe.

2.1.3. *The probe unit circuitry* (figure 1(*b*)). Changes in the carrier oscillator amplitude will affect the calibration and so the amplitude must be stabilized. A single transistor class C bottomed oscillator with a regulated supply is the simplest circuit which gives satisfactory results. However, the 100 kΩ resistance in the base circuit may have to be changed so that the oscillator transistor just bottoms. An oscillator frequency of 600 kc/s was chosen, keeping in mind the discussion on this subject by Tucker and Charnock and the suitability of this frequency for transistor circuits. The linearity of the self-balancing bridge circuit depends on the gain of its amplifier. By using the single transistor, tuned load, amplifier stage of figure 1(*b*), which has a gain of greater than two hundred at the oscillator frequency, the bridge is linear to better than $\frac{1}{2}\%$ and is therefore not the major source of error in the device. A phase sensitive detector is used because temperature effects in the diodes cancel and also because its linearity is satisfactory.

The output of the probe unit may be fed directly to an ammeter, or connected across a small resistance (100 Ω) to an oscilloscope, or as described in the next section into a pen recorder amplifier.

The sensing circuit is designed so that it does not overload until the probe capacitance is equal to the amplifier feedback capacitance. For the circuit drawn in figure 1(*b*) overloading will occur when the probe presents a capacitance of 100 pF. This corresponds to a probe penetration into the water of about 1 ft. A larger feedback capacitance is necessary for the range of the instrument to be extended, or a probe with a smaller capacitance per unit length could be used. By including the 220 pF tuning capacitor of the tuned amplifier in the feedback path parallel to the 100 pF, a capacitance of up to 320 pF could be measured. Waves 3 ft in magnitude could therefore be measured using the probe wire previously described. (Note: the modification does not affect the tuning of the amplifier because the feedback capacitance is part of the tuned load.) If the probe selected for a particular application presented a greater capacitance than 320 pF to the sensing circuit, major alterations would be necessary, i.e. the amplifier load transformer would need to be redesigned. Certainly, however, the circuit techniques used are adaptable to wave measurements of any magnitude encountered in a laboratory.

2.2. *The pen recorder amplifier*

Figure 2 gives the circuit of the amplifier designed specifically to receive currents from the probe unit. The gain of the amplifier depends only on feedback resistors and is therefore stable and can be switched to desired values (see sensitivity control, figure 2). Amplifier drift is not a great problem for wave recorders; however, steps have been taken to reduce it to negligible proportions. (Drift corresponds to a change in average water level and this is usually of no consequence.) The amplifier drives the pen recorder coils and these require ±50 mw full scale deflection driving power and have a resistance value of 1·1 kΩ.

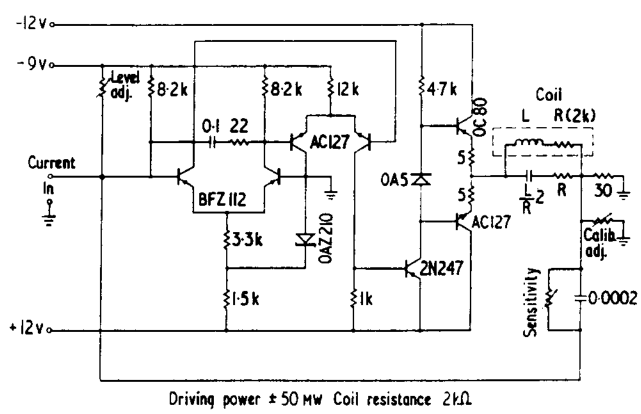

Figure 2. Pen recorder amplifier (current driven).

2.3. *The power supply*

The calibration of the probe unit depends on the magnitude of its power supply voltage, which therefore must be regulated. The Zener diode current in the regulator can be adjusted until the calibration of the complete system is independent of temperature variations.

3. Adjustments and the method of operation of the instrument

In general, it is not convenient to provide for adjustment at the probe head itself because this should be fully sealed. The probe will possibly be in an inconvenient location and so all adjustments must be made at the recording equipment.

Calibration of a probe unit is readily achieved by fully immersing the probe, and adjusting the pen deflection by the 'calibration adjustment' potentiometer shown in figure 2 to read the known length of the probe. (The amplifier sensitivity is, of course, switched to the appropriate value.)

When the probe unit is set up ready for use, the pen deflection can be reduced to zero by adjustment of the 'level adjustment' potentiometer shown in figure 2 and the amplifier switched to the desired sensitivity. Recordings can then be made.

4. The accuracy of the instrument

The linearity and stability of the instrument for steady state conditions was measured by the Department of Civil Engineering at the University of Queensland to be better than 2% for all ranges. (If the instrument has not been adjusted so that temperature effects are negligible, then different calibrations are needed for different ambient temperatures.)

The error introduced by water film adhering to the polyethylene wire and by meniscus effects is dependent not only on the properties of the wire insulation and the wire thickness, but on the waveforms being measured. The author considers that, for the previously described probe, the error is within 2% for waves greater than 3 in. in magnitude and increases as the wave height decreases.

The design of the instrument is such that one could expect that the accuracy with which water level displacement can be recorded is to about 2% for waves greater than 3 in. in height, and perhaps 10% for waves ½ in. in height.

5. Conclusions

The system described above appears to be satisfactory for the present requirements of a hydraulic laboratory wave recording instrument because it is simple, linear and of stable calibration.

Acknowledgments

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