**Mahasagar**–Bulletin of the National Institute of Oceanography, **18**(2). 1985, 347–364.

# TRANSDUCERS AND MICROPROCESSORS IN OCEANOGRAPHIC APPLICATIONS

R.G.P. DESSAI & E. DESA

*National Institute of Oceanography, Dona Paula, Goa* - 403 004.

## ABSTRACT

Transducers used for the sensing of the ten most measured marine parameters have been described in this paper. The ten parameters have been classed under 5 sensor types, namely temperature, pressure, salinity, currents and waves. For each sensor type, attention has been paid to the most promising candidate for the years to come, and an example of a complete instrument using such sensors has been highlighted, especially the contributions that modern day programmable logic can make to instrumentation systems.

The conclusion highlights the areas of transducer technology that the country can enter to benefit the several communities of oceanographers, meteorologists and users in the oil industry and ports and harbours.

**Key-words:** Transducers, Microprocessors, marine parameters.

## INTRODUCTION

A review of the state-of-art of Transducers and Microprocessors in Oceanographic Applications must necessarily be linked to the parameters measured by Oceanographers. It is instructive therefore to first, list those oceanic parameters that are most often measured. In order to arrive at such a list, a survey carried out by Koppen & Etter listed the 20 most measured parameters. These are reproduced in Table I.

In this review are covered the transducers used for the measurement of the 10 most measured parameters, as they are areas in which the greatest efforts are being made, and in which technology is making its most vital contributions.

Transducers, the front end components to measuring systems, need to be assessed together with the entire system and it is important therefore to identify those aspects of Marine Instrumentation that are most important to the Oceanographers. Parker (1978) has formulated the idealised specifications as follows:

1. Survivability
2. Known Response
3. Easy Calibration
4. Self testing
5. High Accuracy
6. Low power

The establishment of programmable logic — microprocessors — in complete systems has also raised questions on the advantages offered by such

Table I. Most measured marine parameters.

| | |
|---|---|
| 1. Ocean Temperature | 2. Air Temperature |
| 3. Sea Surface Temperature | 4. Depth and Bathymetry |
| 5. Barometric Pressure | 6. Wave Height |
| 7. Tides | 8. Salinity |
| 9. Current Velocity | 10. Wave Period |
| 11. Wave Direction | 12. Wind Velocity |
| 13. Nitrates | 14. Silicates |
| 15. Phosphates | 16. Humidity |
| 17. pH | 18. Low Mol. Wt. hydrocarbons |
| 19. Dissolved Oxygen | 20. Nitrates |

components. The added advantages offered by microprocessors to the above criteria are listed below:

1. Lower power; 2. Low chip count; 3. Reconfigurability; 4. Data processing and reduction capability and 5. Programming capability.

It is therefore necessary to consider transducers in conjunction with the conditioning circuitry when assessing complete oceanographic systems.

In the discussion following, the measured will be discussed in terms of the various state-of-art transducers and their advantages and disadvantages. is each case, an example taken to illustrate the gains realised from systems utilising modern transducer technology in conjunction with microprocessors.

## Temperature

The classical oceanographic technique for temperature sampling at different depths is by reversing protected and unprotected glass-in-mercury thermometers (Desa and Desa, 1982). At a classical hydrographic station, such measurements are still routinely made, with temperature accuracies of the order of 0.05 °C and depth values to 2% of full scale. Modern day instruments combine the measurement of several parameters into a single logical unit. One example of such a multiparameter measuring system is the CSTD profiler. The measurement of Conductivity (C), Salinity (S), Temperature (T) and Depth (D), as well discrete water sampling, is more rapidly, comprehensively and accurately done by profiling CSTD probes with rosette sampler attachments for water sampling. We shall describe the temperature sensors, used in these probes, which measure ocean temperatures from the surface to ultimate ocean depths. The measurement of air temperature utilises similar sensors, though the pressure casing necessary for deep water measurements, is omitted.

## Thermistors

Thermistors are often used for the measurement of temperatures with an accuracy of 0.1 °C. Although thermistors have low accuracy and interchangability, they offer very high sensitivity (30 mV/°C) and the measuring circuitry is therefore very simple. Thermistors exhibit a non-linear decrease in resistance with temperature but with the addition of series and parallel resistors fairly linear outputs are obtainable. Another advantage of thermistors is their fast response times, unprotected thermistors with time constants as low as 25 msec. are available.

It may be mentioned here that whilst the cost of thermistors may be low when compared to the other transducers described here, the final cost after packaging for pressure resistance and low thermal response time constants, makes the thermistor fairly expensive even so.

**Platinum Resistance Thermometer**

Platinum resistance thermometers have the necessary precision, and stability required for long term oceanic measurements. Their drawbacks are their slow and non-linear thermal response (Dauphinee and Thomas, 1960). The equation defining resistance R in terms of temperature T on the International Temperature Scale in the range $0\,°C < T < 630\,°C$ of the platinum resistance thermometer is given by :

$$R = Ro\,(1 + AT + BT^2)$$

where A and B are precisely determined constants, correcting the transfer characteristic equation to accuracies better than 1 ppm.

The platinum resistance thermometer is ideal for air-temperature, and sea surface measurements as also for accurate measurements in a slowly varying thermal environment. For profiling work, the slow response of the transducer is a severe drawback, though a novel approach has been used by Brown (1974) to circumvent this.

In the Brown configuration, temperature is measured using a precision platinum resistance thermometer (response time 250 ms) and a miniature high speed thermistor probe (30 ms). The thermistor circuit voltage is automatically nulled in an electronically balanced bridge having a response time equal to the platinum thermometer. Rapid thermistor responses to a changing thermal environment produce a momentary unbalanced output from the thermistor bridge which is equal and opposite to the lag in the platinum thermometer. Thus temperature is sensed with the excellent stability and linearity of the platinum thermometer, though with the speed of miniature thermistors, and without the drawback of thermistor calibration drift.

**Copper Resistance**

Dauphinee and Thomas (1954) has pioneered the use of the copper resistance thermometer for use in the marine field. He has reported the temperature-resistance characteristics of copper wire to be reproducible, enabling the transducer to serve as a reliable precision resistance thermometer. The thermometer is constructed by looping several lengths of 99.999% pure, formel-insulated

No. 40 AWG copper wire into a stainless steel capillary and blowing silicone oil through the assembly to force the copper wires to adhere to the inside of the steel capillary by stiction. One end of the capillary is then sealed and the entire assembly is wound in a spiral, a form which lends rigidity and compactness to the transducers.

The Copper thermometer has a typical resistance sensitivity of 0.252 ohms per °C, and the advantage of a response time better than 25 msecs. Rameshu (1978) has reported the successful fabrication of several prototypes with response times of the order of 50 msecs to 150 msecs and acceptable short term stabilities.

The characteristics of the three temperature sensors described above have been tabulated in Table II.

**Table II.** Sensor for Ocean, Air and Sea Surface Temperature

| Specifications | Thermistor | Copper Resistance | Plantinum Resistance |
|---|---|---|---|
| Accuracy | 0.1 °C | 0.005 °C | 0.003 °C |
| Range | -50 to + 150 °C | –4 to + 15 °C | –220 to + 600 °C |
| Linearity | Non linear | 0.005 °C | Non linear |
| Response Time | 25 m sec. | 20 m sec | 1–10 sec |
| Repeatability | 0.1 °C | 0.005 °C | 0.003 °C |
| Exchangability | — | — | 0 25 °C |
| Stability | 0.1 °C | 0.005 ° | 0.05 °C |
| Sensitivity | 30 mV/°C | 0.2 ~/°C at 10 m A | 0.00385 ~/°C |
| Cost | 100 $ | 2000 $ | 1500 $ |
| Remarks | | | |

In order to illustrate the use of microprocessors with a resistance sensor, a very simple example is taken of a copper resistance thermometer in conjunction with a pressure transducer to sample temperatures at 1 meter depth intervals. The instrument is known as an Electronic Bathy-Thermograph (EBT) and is designed to replace the traditional Mechanical Bathy-Thermograph (MBT). The MBT has a simple mechanical bellows for the sensing of depth, and thermally sensitive fluid in a spiral capillary tube to sense temperature. The bellows moves a goldplated glass slide, over which the sharp end of the capillary scratches the instantaneous deflection arising from the temperature sensor. An entire 275 meter free fall cast is enscribed on a glass slide of 1 inch width and 2.5 inches long.

In contrast the EBT, when switched on, allows the user the option to enter header information to allow for easy identification of the determining characteristics when analysing the data. The instrument monitors the pressure transducer, and as soon as the output changes equivalent to 1 meter, the temperature sensor is sampled. The value taken in, is corrected against a second order polynominal, or a thermister look-up table (as appropriate) and the temperature accurate to one decimal in degrees Celsius is written onto semiconductor memory.

On retrieval, the data can be played back onto an 18 column printer, a VDU terminal, or displayed on LEDs. It is obvious that the overall EBT instrument is as far removed from the older MBT as the newer thermometers are from the capillary thermometer types.

The use of modern day transducers deserve modern day circuitry, to afford the oceanographer more conveniences and free him from the drudgery of collecting routine data in a tiresome way.

**Pressure**

In discussing pressure, it is appropriate to mention Bathymetry as well since in oceanographic surveys, water depth is a routine measurement. The normal techniques for the measurement of depth, as also for side scan sonar and seismic profiling, belong to the general class of acoustic transducers.

We shall confine our discussion to only one sensor here, the quartz pressure transducer, as this transducer exhibits great accuracy, repeatability and low hysteresis, and in our view will be the single most important pressure sensor in the decade to come for use in the marine field.

**Quartz pressure transducer**

Paros (1973) has reported the design of a digital quartz pressure transducer suitable for oceanographic work. He has reported its use in water level sensing and recording systems, and for the monitoring of barometric pressure for studies on atmospheric disturbances.

Joseph and Desa (1984) have reported their use in tide level recorders suitable for storm surge recording as well as long term deployment as tide guages. Use of the differential transducer in this application bypasses barometric pressure variations and results only in a true water-column reading.

The Paros report indicates that the key sensing element in the pressure transducer is a quartz crystal oscillating beam whose resonant frequency varies with the load. Quartz crystal was chosen as the material has excellent elastic properties, long term stability characteristics and is relatively insensitive to temperature variations.

The constructional details of the quartz crystal resonator is shown in Figures 1 and 2. The further design considerations considered by Paros included:

1. Capability to make differential pressure measurements as well as measuring absolute and gage pressures.
2. Isolation of the pressure media from the quartz resonator since the crystal works in a vacuum.

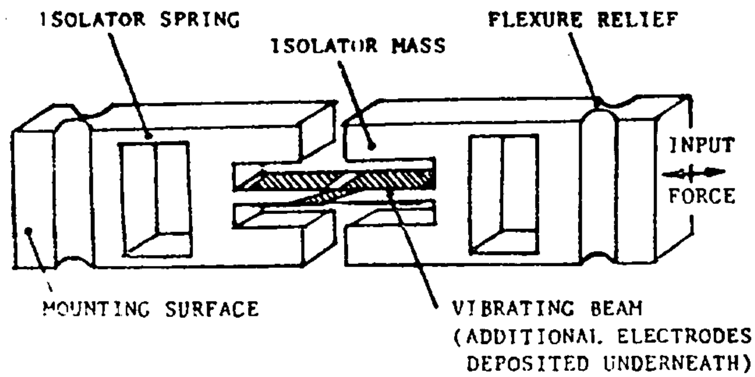


Fig. 1. Quartz crystal resonator.

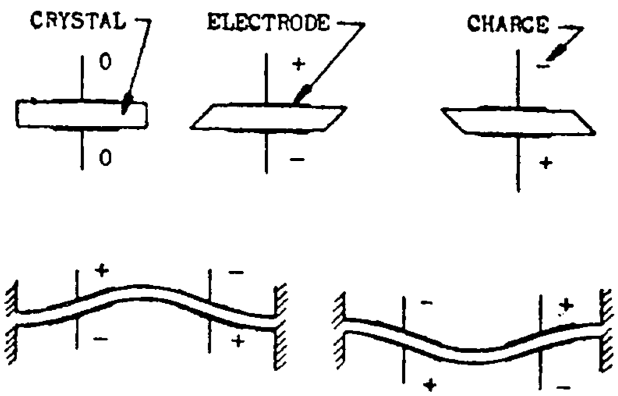


**FIGURE 2. Piezoelectric excitation.**

3. An acceleration-compensation scheme to reduce the sensitivity to external forces and transducer orientation.
4. Capability to easily scale the transducer for a variety of pressure ranges.
5. Pressure-to-force converter and suspension arrangements which do not degrade the quartz resonator performance.

The actual configuration used in the transducer is shown in Figure 3 which is a basic differential pressure transducer. The balance weight shown in the diagram is so positioned as to avoid acceleration effects.

The considerations of stability, reported by Paros, can best be seen from Figure 4, wherein atmospheric pressure changes as low as 0.03 millibar can be detected.

The equations governing the output frequency of the transducer to the input pressure is given by:

$$\text{Pressure} = A\,(1 - To/T) - B\,(1 - To/T)^2$$

where :

T = period output

To = period output at zero pressure input

A, B = Curve fit coefficients.

It is the non-linear characteristics balanced by the extremly favourable transducer characteristics that make this unit an ideal candidate for incorporation with a microprocessor. Such a system has been reported by Joseph and Desa (1984) in a microprocessor based tide measuring system. The automatic selfrecording tide gauge used an Intel 8085 processor and erasable programmable read only memories (EPROMs) for data storage. User friendly features were built into the instrument that permited the user to inspect or obtain hard out puts of data at the recording site or in the laboratory in linearised

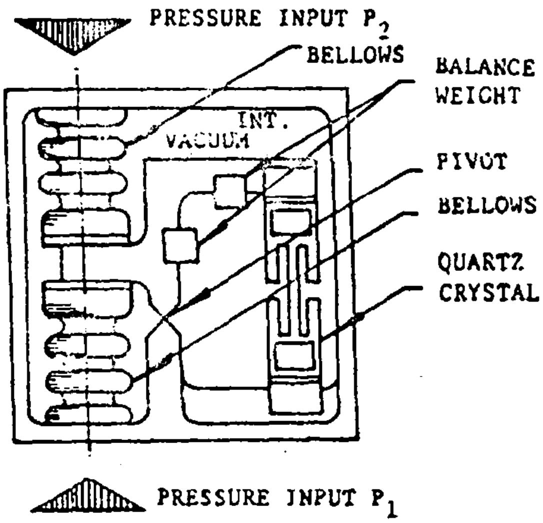


Fig. 3. Differential Pressure Transducer.

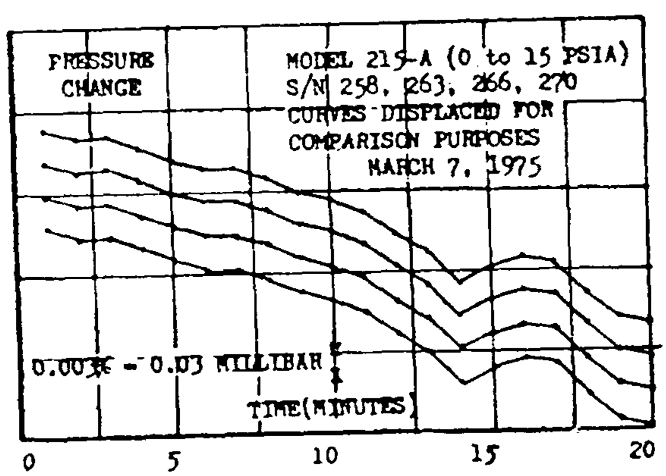


Fig. 4. Barometric tracking.

engineering units. The software for the instrument performed the following essential functions :

(i) The time period T of the sensor output was accessed by the CPU and stored on RAM.

(ii) A novel method of using the Intel Floating Point Arithmetic (FPAL) routines evaluates the sensor polynominal and stores the computed data.

(iii) The tidal signal was sampled 512 times, and the average value written into EPROM.

(iv) At the end of the data acquisition routine, an audible beep is generated to signal the end of the data acquisition.

The microprocesses-based tide gauge described above is a good example of using a processor to acquire and present data from a highly accurate transducer to the user in an understanable form.

The various specifications of the quartz resonator transducer vis-a-vis the more common strain gauge sensor is given in Table III. The pressure transducer can be used in the measurement of depth, wave height, and tides from bottom mounted transducers. When used for measuring wave height in this manner, care must be taken to account for the attenuated wave effect with depth.

**Table III.** Sensors for Pressure, Depth, Wave height and Tide.

| Specifications | Strain Gauge | Quartz |
|---|---|---|
| Accuracy | + 0.05% | 0.025% |
| Range | 0–350 meters | 0–60 meters |
| Linearity | 0.5% | Non linear |
| Response Time | 1 m sec | 1 m sec |
| Repeatability | 0.1% | 0.005% |
| Exchangability | — | N.A. |
| Stability | 0.2% | 0.008% |
| Sensitivity | 0.5 m V/BAR at 15 V Excitation | — |
| Costs | 5000 Rs | 3000 $ |
| Remarks | Strain gauge transducer from ISRO | Digiquartz pressure transducer from Paroscientific U.S.A. |

## Salinity

Salinity measurements in the oceanic environment present a challenging problem as the sensor must respond rapidly to changing salinity, be insensitive to electrical noise from the ship, as also physical noise induced by transferred motion of the ship to the profiling instrument.

Salinity changes affect the dielectric constant, index of refraction, electrical conductivity and velocity of sound in water. Salinity sensors have been designed based on all these properties (Greg and Pederson, 1980). Sankaranarayanan (Private Communications) has reported success with inductively completed ferrite cores, though sensitivity to humidity, pressure and contaminated cores could give rise to poor repeatability. Further, the inductively coupled cell cannot be readily scaled down in size for microstructure measurements without loss of accuracy due to electrical problems. The most popular modern day sensor is the conductivity type of sensor. This sensor uses a 4 conductor scheme in 4 glass arms. Such a scheme avoids the problems of electrode polarisation and allows extremly accurate conductivity measurements to be made. The electrodes are composed of 90% platinum and 10% iridium wire. The sensor has the particular advantage that conductance — defined as the ratio of current through the "current electrodes" to the open circuit voltage at the "potential electrodes" — is independent of polarisation impendance effects. These effects are due to electro-chemical reactions at the electrode/electrotype interface and are very dependent on surface cleanliness of the electrodes in the two conductor sensor scheme. The 4 conductor type of cell can be readily scaled down in size for microstructure work, though it should be noted that a small cell will be inherently more sensitive to the effects of deposits on the walls, simply because a given thickness of a deposit represents a large fractional change in apparent wall dimensions. These deposit are believed to be calcium/and or magnesium carbonates on the inner walls of the cell.

Salinity is computed from conductivity, temperature and depth, and all three parameters are measured by profiling CTD probes for the calculation of salinity.

It is of interest to note the circuitry considerations that go into the design of a viable field-worthy conductivity instrument. Figure 5 (Mesecar and Wagner 1981) gives the block diagram of a typical 4 electrode conductivity cell and measuring circuit. One of the "limitations" of the sensor, arising from its geometry, is the existence of an exterior signal current path. Thus current can travel from E4 to E1 both within and without the cell. This exterior current flow causes the cell to be sensitive to the external environment, notably the steel cable supporting it and carrying down the ship's electrical noise. One way of reducing the current path is to place guard electrodes between E4 and the cell end. This however brings in an attendant problem of shunting a large fraction of the drive current and causing a drop in the cell's sensitivity.

A second limitation is the susceptibility of E1 to extraneous signal currents. This electrode picks up currents not only from E4 but from other sources as well. The technique of placing another guard electrode has the same effect as for E4 described above.

A third limitation is the effect of polarisation voltages which slowly build up with time on the "current electrodes". Further corrective circuitry has to be incorporated to generate a cancelling voltage to this polarisation

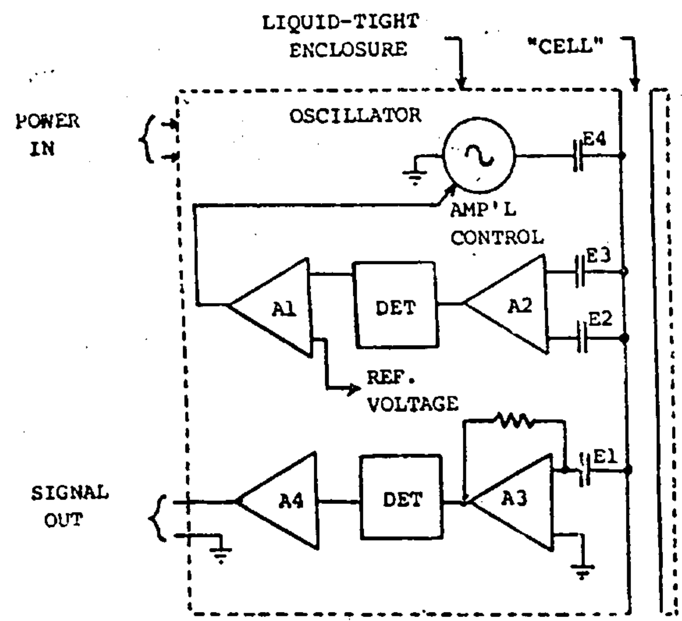


Fig. 5. A block diagram of the Conductivity cell and measuring circuit.

effect, which if allowed to build up forms bubbles on the electrode surface masking it from passing further current through the cell.

D'Souza, Peshwe, Desa and Manoharan (1980) have reported a profiling CTD instrument tested off the Andaman Sea. The instrument had the following specifications :

| | | |
|---|---|---|
| Conductivity Range | : | 2–13 mmhos |
| Conductivity Accuracy | : | ± 0.05 mmhos/cm |
| Temperature Range | : | 0 to 40°C |
| Temp. Accuracy | : | ± 0.05°C |
| Depth range | : | 700 meters |
| Depth Accuracy | : | 1% of full scale |

The instrument uses a square wave oscillator and derives 4 waveforms to drive the conductivity and pressure circuits and to use for demodulation. The conductivity circuit maintains the "potential" electrodes at a constant potential through a feedback loop.

The instrument had the following features :

a) Raw CTD data could be recorded for later play back.

b) Salinity was computed on-line from the C, T and D inputs. This was advantageous as circuit derivations of salinity could suffer from additional drifts and errors.

The equations that are used for the calculation of salinity Sc, are those of Cox.

$$Sc = -0.08996 + 28.29720\ Rc + 12.80832\ Rc^2 - 10.67869\ Rc^3 + 5.98624\ Rc^4 - 1.32311\ Rc^5$$

$$Rc = \text{Function } (Rt,\ T)$$

$$Rt = \text{Function } (T)$$

where Rc and Rt are conductivity ratios of the *in-situ* measurement to standard sea water of 35 ppt chlorinity and T is the measured temperature difference from 15°C.

The further use of microprocessors in this system design can be in the slowing down of the conductivity response to bring it to the speed of the temperature sensor. If the two sensors do not have the same order of magnitude response, the system will show up salinity "spikes" where the "spike" is generated because the salinity is calculated from a "new" conductivity value and an "old" temperature value.

**Currents**

The measurement of currents is one of the more difficult measurements to make in the marine field. Marine scientists have been finding that the movement of waters is much more complex than previously thought. Among the earlier techniques of measuring current, were the rotor or impeller type of current meters (Canon & Pritchard, 1971). These are still widely in use. Their deployment however is prone to produce large errors and one must have some idea of the type of flow regime one is deploying them in to be aware of the type of errors that can influence the results. A wide range of current meters have been designed using acoustic travel time sensors (Lawson, 1976), electromagnetic sensors (Olson, 1972), and laser doppler velocimeters.

**Acoustic Travel Time Sensors** (ATT) :

These sensors measure the travel time difference of sound simultaneously in opposite directions along the same acoustic path. Two or more such paths are used to establish the flow vector. These sensors have a fast response and are inherently linear. Individual transducer elements are relatively inexpensive and are easy to multiplex. Three detection techniques for ATT Sensors are in general use.

a) Pulse Edge Detection : Acoustic pulses are transmitted simultaneously from two transducers. When received, the arrival time difference of a zero crossing of the received pulse is measured.

b) Continous Wave : Continous acoustic signals are transmitted in opposite directions and the component of the total phase shift caused by the fluid motion is measured.

c) Sing — Around : In this method a pulse is transmitted and on reception a second pulse is generated. In this way a "sing around" frequency is established which is directly proportional to the total travel time in one direction. Reversing the transmitter and receiver establishes the sing-around frequency in the opposite direction. The difference of the two frequencies is a measure of the desired speed component along the acoustic path.

**Electromagnetic (EM) Sensors**

The parameter sensed by an EM flow meter is the electric potential gradient, E, between two electrodes, in a magnetic field B, sensing the flow, u, of a conductive medium such as sea-water. The vector expression is given by:

$$E = \underline{u} \times B$$

The main draw-back of the EM flow sensor is in the disturbances to flow that the sensor introduces. For a field worthy instrument, a practical rugged sensor shape is required and many types have been tried including the cylinder, disc, sphere and open coil. Each shape has some disadvantage, though the open coil system (Olson, 1972) seems the most promising. It has not however attracted enough interest mainly because as the coil is made larger (for lower flow interference), the control of electrical leakage becomes more difficult (Griffiths and Collar, 1980).

The EM sensor has many advantages, and with the availability of low noise, high gain operational amplifiers, the problem of amplifying the low level electrode voltages is quite tractable. The packaging of the sensor however limits the EM sensor in ocean research, not the electronic, electro-chemical, power or signal-processing problems.

Many commercial equipments are available utilising this sensor. They can be made small, rugged, low drift and very sensitive. Desa and Desa (1978) have reported on an EM flow-meter and this is discussed in more detail later.

**Laser Doppler Velocimeter (LDV)**

The laser doppler velocimeter is well suited for small scale observations. In this technique, two crossed, spatially coherent beams from the same laser are made to illuminate a small test volume. The beams set up regular, spaced, parallel planes of interference normal to the plane of the laser beam. Small particles moving through the planes scatter light of varying intensity as they pass through the interference zones. The modulation frequency F, is given by:

$$F = 2Vn \sin \theta / \lambda$$

where V is the particle velocity normal to the planes of interference

n is the refractive index of the fluid

$\lambda$ is the laser wavelength in free space

$\theta$ is the half angle between the laser beams

The laser Doppler technique provides a good tool for the measurement of small scale flows. It has the following advantages:

a) the calibration is dependent on n, and o all of which are stable and reproducible.

b) the sensor has good time and space resolution.

c) the measurement is made at a location remote from the instrument, thus leaving the flow regime undisturbed.

We describe now a closed-loop electromagnetic flow-meter (Desa and Desa, 1980). An electro-magnetic current sensor of the open coil type described by Olson, (1972) was designed and built using graphite electrodes as the sensing elements. The magnetic field was produced by Helmholtz coils and were excited sinusoidally. In order to conserve battery-power, the amplified electrode voltage was rectified, demodulated and fed to the coil oscillator circuit to change it in a direction so as to always maintain the electrode voltage constant. A block diagram is given in Figure 6. In conditions where a large range of velocities is encountered, say from 5 to 200 cms/sec (which would be typical in an estuarine environment), the saving of power could be in excess of 1000 times that of steady-level excitation.

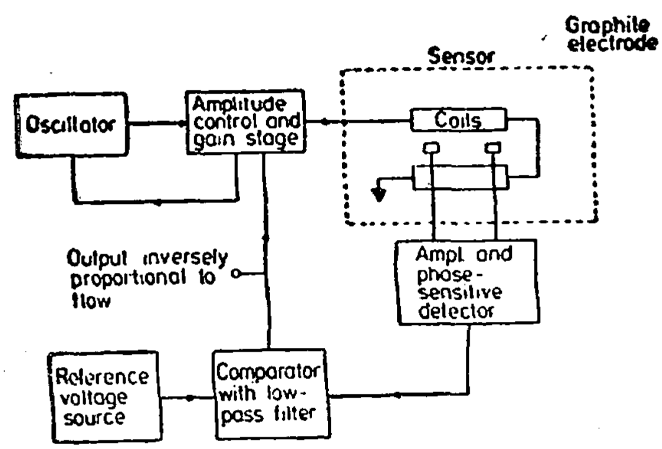


Fig. 6. Block diagram of the closed-loop electromagnetic Flowmeter system.

Since the system operates to maintain a constant voltage at the electrodes, Vref, we have:

$$\text{ref.} = uBl$$

where "l" is the distance between electrodes.
Since B is directly proportional to the voltage across the coils, Vc,

$$u \propto Vc^{-1}$$

The coil voltage, Vc, is therefore inversely proportional to the flow velocity.

Such an instrument as described above, and completed in 1978, would have benefitted enormously from the present crop of low-power CMOS microprocessors. Incorporation of a processor in the instrument would allow the system to check the sensitive front end amplifiers for drift and polarisation effects, and also carry out preliminary self-tests on switch on. Moreover, the inversion of the coil voltage to directly read flow in cms/sec would be a straight forward task, as would be the incorporation of a non-linearity look-up table that would allow read-out in linearised engineering units.

The specifications for the EM sensor are given in Table IV. The specifications for the acoustic travel time sensor and the laser doppler velocimeter are not tabulated, as these are still in the development stage and no firm specifications exist.

**Table IV.** Sensor for Salinity/Conductivity.

| Specifications | 4. Electrode sensor |
|---|---|
| Accuracy | 0.005 ppt |
| Range | 28–40 ppt |
| Linearity | 0.005 ppt |
| Response Time | 50 m sec |
| Repeatability | 0.005 ppt |
| Exchangability | No |
| Stability | 0.002 ppt (6 months) |
| Costs | 2000 $ |
| Remarks | |

## Waves

Waves are a complex phenomena to measure and it is probably safe to say that a universal wave recorder may never materialise (Draper, 1971). This is because the type of sensor needed for the measurement of waves differs with what one wishes to measure in a given situation. We can, however, classify the type of situation as wave measurements to be made in shallow and deep waters and further subdivide them as sensors to be located either on the surface or the bottom.

### Surface deployment

One of the earliest wave recorders was known as the Spark Plug Wave Recorder, in which a series of spark plugs was held horizontally and separated from each other by fixed distances. The disadvantages of such a system was that an offshore structure was needed to clamp the spark plug arrangement. Another early type of sensor for shallow water was the through surface sensor in which a resistance wire or an insulated wire, to measure capacitance, was vertically strung to pierce the surface of the water. Variations in resistance or capacitance were a direct measure of surface wave activity.

One of the most popular surface deployed wave recorders now in use is the Wave Rider Buoy. The Waverider measures wave height without using a reference point at sea. By integrating the signal twice, displacement is obtained. This displacement is the wave height related to the vertical displacement. The vertical direction is the direction of the gravity force and the accelerometer has therefore to be supported on a gravity seeking system which in this case is a gravity pendulam. Several considerations must be taken into account in the design of the platform especially protection against horizontal

**Table V.** Sensor for Current Velocity.

| Specifications | Electromagnetic |
|---|---|
| Accuracy | 1 mm/sec |
| Range | 0–5 m/sec |
| Linearity | 0.1% |
| Response Time | 20 sec |
| Repeatability | — |
| Exchangability | — |
| Stability | 1 cm/sec/month |
| Sensitivity | 36 $\mu$V/knot<br>18 $\mu$V/meter/sec |
| Costs | 2000 $ |
| Remarks | |

accelerations which are indistinguishable from gravity forces. Suffice it to say that the natural frequency of the pendulam is made as low as possible and the entire system is made "floating", in a liquid with nearly the same specific gravity as itself. The accelerometer in the Waverider is a cantilever and the spring mass is the mass of the cantilever itself. The deflection of the cantilever is measured by allowing its free end to contact a conducting liquid which has a highly linear A.C. potential gradient set up in it by two electrodes. Thus a deflection of the free end of the cantilever results in a potential change of the cantilever which is linear with deflection and hence with acceleration. The output of the sensors are double integrated and transmitted to shore via a radio link. This information can be received upto 50 kms. away. The main disadvantage in this system is that since it is surface deployed, it is liable to damage from vessels, drift wood and pilferage.

**Bottom deployment:**

A type of bottom mounted transducer for shallow areas is the ultrasonic wave gauge. The sea unit of this gauge consists of a single ultrasonic transducer mounted in a rigid platform fixed securely to the sea-bed, and connected to the deck unit electronics via a waterproof cable. On energising the transducer, pulses are beamed upwards to the water-air interface and the measurement of wave height is based on the first return echo received by the transducer.

A variation on the theme of the bottom mounted transducer is employed by the Ospos Wave Recorder in which a pressure transducer is moored at mid-depth. This has the advantage of being below the surface and is thus immune to the damaging effects described earlier. It also has the advantage that the pressure transducer is brought closer to the surface and therefore "sees" lower attenuation of the surface waves.

We describe now an ultransonic wave-gauge reported by Desa, Desa and Desai (1985), as a special type of instrument that would benefit from the inclusion of a microprocessor in the system. The instrument functions as an inverted echo-sounder, and uses a single ultrasonic transducer placed on the sea-bed. The wave measurements are recorded on a chart recorder, and simultaneously digitised on a printer for subsequent spectral analysis of the

**Table VI.** Sensors for Waves.

| Specifications | Accelerometer |
|---|---|
| Accuracy | Better than $\pm$ 0.2% |
| Range | + 20 m Amplitude<br>2–30 sec period |
| Linearity | Better than $\pm$ 0.2% |
| Repeatability | Better than $\pm$ 0.2% |
| Horizontal Sensitivity | Less than 3% of vertical |
| Remarks | Wave Rider Buoy, Datawell Accelerometer. |

data. The power spectra derived from field data of this instrument compares favourably with spectra computed from wave data measured by an accelerometer wave rider buoy.

From simple model calculations on the distortion of wave data by the ultrasonic wave gauge, it is seen that the beamwidth and operational depth of the transducer have an important influence on the response of the system. It is in this area that inclusion of a microprocessor contributes greatly to the system as a whole in the computation of the spectral density functions. The fourier transform of the correlation function gives a raw estimate of the true power spectral density function, and to reduce the variance of these estimates, a frequency smoothing procedure using the Hanning lag weighting function has to be applied. All of these computational procedures need to be processed online so that the experimenter can be furnished with processed data wherefrom he can identify if the spectral density curves follow the expected trends. This is important in that corrective action can be taken to remedy the field instrument if processed data is not as expected. Such decisions are more authoritatively made from "processed" data rather than from "raw" data.

Such systems, using modern transducer technology, coupled to the new breed of programmable logic devices, results in compact, reliable, instrumentation.

## Conclusions

We have in this paper presented some oceanographic sensors that we expect will play an increasingly important role in marine instrumentation in the years to come. The fabrication of sensors is a challenging task and one that the country must be involved in.

## Temperature

Even though thermistors and platinum resistance thermometers are fabricated in the country, these sensors are still to be designed and packaged for use in the marine environment. It would also be of interest to pursue the development of quartz temperature transducers for marine use. This type of sensor is only now gaining importance in laboratory calibration tests, and entering this field at this stage will ensure that we are at this leading edge of technology.

## Pressure

The quartz pressure transducers have established itself as the pressure transducer for high accuracy work. It is an area which must be pursued at all costs. Accurate pressure transducers are of critical importance in the oceanographic field, meteorology, ports and harbours, and aero-space industry.

## Waves

Wave measurements are of interest to oceanographers, the oil and gas industry, ports and harbour installations and the aero-space industry. The accepted accelerometer wave sensor is from Ms Datawell, a Dutch company, and even an exact copy of the present accelerometer would be of immense benefit to several agencies in the country.

Finally, it has been stressed that the intelligent combination of programmable logic circuitry and high transducer technology, produces instruments that are more accurate and more reliably measure the desired parameters. It would be advantageous for transducer manufacturers to work in close conjunction with some associated leading instrument manufacturers to evolve transducers that can best take advantage of the new devices becoming available daily.

## ACKNOWLEDGEMENTS

The Authors wish to thank Dr. V.V.R. Varadachari, Director, for the laboratory facilities and encouragement.

## REFERENCES


Brown Neil L., 1974. A Precision CTD Microprofiler, *Proceedings of the I. E. E. E. Conference Oceans*, **74** (2) 270–277.

Cannon, G.A. and E.W. Pritchard. 1971. Biaxial propeller Current meter system for fixed mount applications, *Journal of Marine Research.*, **29**: 181–190.

Dauphinee, T.M. and H. Preston Thomas 1954. A copper Resistance temperature Scale. *The Review of Scientific Instruments*, **25** (9): 884–886.

Dauphinee, T.M. and H. Preston Thomas, 1960 Direct Reading Resistance Thermometer. *The Review of Scientific Instruments*, **31**: (3): 253–257.

Desa E.S. and E. Desa. 1982. Transducers for Oceanographic Studies. *Journal of Instrument Society of India*, **12**, (2): 1–14.

Desa E. and E. Desa. 1980. A closed Loop electromagnetic flowmeter. *Journal of Physics E Scientific Instruments* **13**, (2): 233–235.

Desa E.S., R.G. Prabhu Desai and E. Desa. 1985. An Ultrasonic Wave Gauge. *Journal of Physics E. Scientific Instruments* (In Press).

D'Souza O; V.B. Peshwe; E. Desa and Manoharan 1980. An Indigenous Profiling CTD for Deep Water Measurements, *The Andaman Sea Technical Report* NIO, India.

Gregg M.C. and A.M. Pederson 1980. High Resolution Salinity measurement techniques, *Air-Sea Interaction*, Edited by F. Dobson, L. Hasse and R. Davis, Plenum Press, New York: 399–412.

Griffiths G. and P.G. Collar 1980. Some Comparative Studies on Electromagnetic Sensor Heads in Laminar and near-turbulant flows in a towing tank. *Proceedings of the I. E. E E. Conference Oceans 80*, Seattle.

Joseph A. and E.S. Desa. 1984. A Micropropcessor Based Tide Measuring system. *Journal of Physics E. Scientific Instruments*, **17**: 1135–1138.

Koppen, S.E. P.C. Etter. Marine Instrumentation: An Assessment of Technology VS Needs, MAR INC, M.A. *Proceedings of the I. E. E. E Conference Oceans* **78**: 164–173.

Lawson, K.D., N.L. Brown, D.H. Johnson and R.A. Matley 1976. A three axis acoustic current meter for small scale turbulence. *Instruments Society of America* Pittsburg. Pa., ASI. **76269**: 501–508.

Mesecar R. and J. Wagner. 1981. Description of a Folded Five-Electrode Conductivity Cell for Towed Applications. *Proceedings of the I. E. E. E Conference Oceans*, **81**: 489–495.

Olson, J.R. 1972. Two Component electromagnetic flowmeter *Marine Technology Society Journal* **6**(1): 19–24.

Pinkel, R. 1980, Acoustic Doppler Techniques *Air Sea Interaction* edited by F. Dobson, L. Hasse and R. Davis, Plenum Press, New York: 171–199.

Parker, A.G. 1978. Instrumentation — All at sea. I.E.E.E. *Journal of Oceanic Engg.* OE-3 No. **4**: 191–199.

Paros M. Jerome, 1976. Digital Pressure Transducers, *Measurements and Data* Issue 56, 10 (2): 1–14.

Paros M. Jerome, 1973. Precision Digital Pressure Transducer *ISA Transactions*. **12**(2): 173–179.

Rameshu C. 1978. A Fast Response Underwater Temperature Sensor. *N. I. O. Internal Report No. 05/78*