THE SYSTEM DESIGN
2. THE SYSTEM DESIGN

The various components, circuits, controls, displays and sensors are designed for maximum ruggedness, reliability, portability, easiness of operation, very low power consumption, low voltage single supply and very low weight and bulk using the latest state of art in electronics and instrumentation. Rugged and sea worthy sensors with strong signals and facility for remote operation is the most important factor for achieving the above goal. This point has been given top priority throughout the design and development of the system.

2.1 WATER CURRENT SENSOR

Water current sensor forms one of the important parts of the system. The design of the under water system is done mostly to cater the needs of the current measurement.

2.1.1 THE ESSENTIAL FEATURES OF WATER CURRENT TRANSDUCER

For a sound, reliable, accurate and easy method of measurement of water current the transducer should have the following features.

1. Strong signals at low impedance so that they are immune to noise and hence can be conveyed through ordinary long cable.

2. The signal should be free from environmental effects.
3. Simple design.
4. Low power requirements.
5. Operation independent of other factors.
6. Minimum wear and tear, so that occasional calibration can be eliminated.
7. Easy replacement of the rotor to eliminate the need for occasional calibration.
8. Easy method to check the accuracy and performance.
9. Streamlined design with facilities for automatic stabilization to avoid errors due to the drag and tilt of sensor.

Considering the above features and the various techniques available at present, rotor with vertical axis is found to have maximum advantages. Rotor and impeller have almost same basic operational features. Rotor has an additional plus point over the impeller that it works independent of the current direction. The impeller responds to the current magnitude fully only when its horizontal axis is aligned to the water flow. This system has got the required tail and swivel joints for aligning it to the water flow. But when the flow is very low, the hydrodynamic force on the tail is too low that it fails to align to the direction of water flow. Under this conditions the impeller responds to only a component of the water flow depending on its alignment angle (see Fig.1-A). But this
The diagrams show how the misalignment affects the current response.

**Fig. 1.**

A. Impeller current sensor (view from above)

Current response affected by $\cos \theta$

B. Rotor type current sensor (view from above)

Current response is not affected by the angle $\theta$. Because the rotor has got equal response to all directions.
problem does not affect the rotor type sensor. Because the rotor is unidirectional. It has got equal response to all directions in the horizontal plane (see Fig.1-B). Hence savanious rotor was selected for water current measurements because of its unique advantages and simple design.

2.1.2 ROTOR WITH ELECTRIC INDUCTION

Though savanious rotor has got several advantages as mentioned above, its biggest problem is that it is subjected to mechanical or magnetic loads while producing electrical pulses. The rotor sensor can be made more reliable with better threshold features, and repeatability if its mechanical or magnetic load could be eliminated. The solution of this problem resulted in the development of the new technique called 'rotor-induction' as explained below. It is a fact that rotor or impeller along with 'hall diode' does not cause the magnetic or mechanical load as reviewed in the introduction. But it requires fairly large impeller/rotor for accommodating the powerful magnet used for activating the hall diode.

The basic principle used in the 'rotor-induction' method is that the inductance of an electric coil is altered as the value of the permeability of its core is altered. Here a coil is used in the stator and a very thin (about .5mm) ferrous piece of approx. 1.5 cm. dia mounted on the rotor used to change the inductance of the
FIG 2  ROTOR (ELECTRIC) PART OF THE INSTRUMENT

Water current sensor using ferrous core and coil.
former when the latter passes near, along with the rotation of the rotor. The ferrous piece could be moulded in plastic and concealed on the rotor plate. Though the signal is low, it is at very low impedance and hence could be made immune to noise. This signal could be conveyed through ordinary 2-core cable without any noise problem. The details of the assembly of the system are given in Fig. 2. It is obvious that minimum distance is needed between the coil and the core for achieving maximum signal output. But as a practical case, at least 2-3mm gap is needed between the stator and rotor. Considering other practical limitations the distance between the core and coil could be fixed between 4-6mm. The ferrous piece alters the inductance of the coil once in every rotation of the rotor. The above signals in the form of changes in inductance of an electrical coil is conveyed through ordinary unshielded cable to the display meter on board the vessel without any problem of noise penetration which is obvious from the clear signals available at the output of the amplifier, as given in the Fig. 3. The figure shows the graphs plotted by a high speed recorder with the pulses against time. The pulse frequency is altered from almost zero to approx. 18 corresponding to speeds 0 and 440 cms/sec, respectively. The graph shows that the amplitude is not at all affected by the wide range of frequency variation. The shapes of pulses in
Fig 3. The pulses corresponding to the rotation of rotor (electric induction) and produced at the output.
maintained sufficiently uniform. No traces of noise is found in the graph.

2.1.3 ROTOR WITH MAGNETIC INDUCTION

Rotor with magnetic induction is already existing in some of the current meters, eg. the current meter manufactured by Aanderaa Instruments, Norway. It has got advantage that its associated electronics is very simple. Wherever a larger rotor can be accommodated, this method is much inexpensive. Its rotor has to be slightly larger than the 'electric induction' type as it has to carry one magnet for activating the reed switch mounted on the stator, as shown in Fig.4. Rotor with magnetic induction was designed and fabricated with the following features.

1. Dimensions of rotor .. 80 mm dia x 78 mm length
2. Thickness of material .. 1 mm
3. Material .. high density polypropylene
4. Dimensions of magnet .. 4 mm dia x 25 mm length
5. Size of reed relay .. 3 mm dia x 20 mm length, gold plated contacts
6. Maximum distance allowed between magnet and reed switch to make a contact .. 9 mm
7. Weight of rotor without magnet .. 35 gms
8. Weight of rotor with magnet .. 47 gms

9. Mountings of rotor .. Stainless steel pins with brass sockets

As the magnet passes near the reed switch once in every rotation, the switch is activated making a switching contact from its normally opened condition. The switch remains 'on' in the presence of the magnet until the magnet moves sufficiently away from the reed switch.

The pulses from the reed switch were examined and found to have the required perfection free from transients and external noises, which is obvious from the recordings on paper chart as given in Fig. 5.

2.1.4 SPECIFIC ADVANTAGES OF ELECTRIC ROTOR-INDUCTION METHOD

The following are specific advantages gained by this method.

1. No wear and tear while producing the required pulses. This increases the longivity of the associated parts.

2. No additional load is caused while producing the pulses. This has reduced the threshold value of the detected current.

3. The rotor could be made much smaller compared to the conventional types. This has resulted in much compact and convenient type current-meter.
Fig. 5. The pulses corresponding to the rotation of rotor (magnetic induction) and produced at the collector of amplifying transistor.
4. The sensing elements can withstand any reasonable hydrostatic pressure. This has eliminated the need for a pressure chamber which usually makes current meter probes bulky and heavy.

5. As the rotor is quite small and light, it could be mounted on two pins thereby making the design simpler. It is independent of other parts and electronics of the equipment. Hence the maintenance and checking are easy. The rotor can be replaced easily.

The physical features of the rotor are:

1. dimensions  ..  55 mm dia x 78 mm length,
                   5 Nos. blades

2. material      ..  high density polypropylene

3. mountings     ..  stainless steel pins with brass sockets as shown in figure.

4. dimensions of ferrous piece  ..  15 mm dia, 0.5 mm thick

5. weight of rotor ..  29 gms in air

6. Relative permeability of material  ..  above 500
2.2 DIRECTION SENSOR

The direction of water current is sensed as changes in electrical resistance of a potentiometer. The following are the features and components related to the process.

1. The shape of the complete underwater unit along with the vertical and horizontal fins and the swivel suspension system which allows the underwater probe to be aligned in the direction of water flow.

2. Potentiometer resistance fixed in the underwater system moves along with the complete system.

3. Magnetic compass pivoted for free motion and mounted inside the potentiometer, aligns to earth's magnetic north.

4. Potentiometer stylus which makes a contact on the potentiometer resistance whenever needed so. This stylus mounted on the magnet makes always a reference to the earth's magnetic north as it is mounted on the compass. Thus the stylus position on potentiometer makes a signal in relation to the relative positions of the potentiometer (which refers to the current direction) and the earth's magnetic north. The electrical signal is obtained as changes in electric resistance from 0 to 2000 ohm corresponding to the direction 0 to 360°.
5. Energising coil. Normally the stylus is free from making a contact so that the magnet can freely align to Earth's magnetic north. When a current is passed through the energising coil which surrounds the compass and potentiometer, the magnet is pulled perpendicular to its direction of motion so that the stylus mounted on it makes a contact on the potentiometer. After making measurements, the coil is deenergised enabling the compass to align to the new direction.

A commercially available direction sensor was used with the features as given below and drawing as per Fig.6.

2.2.1 FEATURES OF MAGNETIC DIRECTION COMPASS

1. Manufactured by M/s. Aanderaa Instruments, Norway
2. Dimensions 53 mm dia x 33 mm height
3. Exciting voltage 6 V
4. Required current 15mA
5. Allowable tilt 12°
6. Weight in air 92 gms
7. Potentiometer resistance 2000 ohms
8. Damping oil damped
9. Response time less than 5 sec for 90° angle
10. Accuracy ±2°
The compass was designed for ordaining current meter application, but can be used for many other purposes. This compass, when used with a potentiometer, allows the magnet assembly to be read. When the magnet assembly is to be read, the clamping coil must be interrupted for a few seconds to allow the magnet to swing towards north, having been altered during the reading.

Specifications:

- Clamping voltage: 6 Volts
- Clamping current: 1 mA
- Potentiometer resistance: 10 kΩ
- Allowable tilt: ±5°
- Accuracy: Better than 1°

Sudden changes in the compass reading may occur, but the compass will return to normal within a few seconds.

Clamping coil:

Potentiometer:
2.3 TEMPERATURE SENSOR

Thermistor was used as the basic sensing element. Thermistor is a semiconductor material which undergoes resistance variation inversely proportional to temperature. This variation in resistance is given by

\[ R = R_0 \exp \left( \frac{B}{T} \left( \frac{1}{T} - \frac{1}{T_0} \right) \right) \]

where \( R_0 \) = resistance at reference temperature
\( T_0 \) = \( ^\circ \text{k} \), \( R \) = resistance at temperature
\( T \) (\(^\circ \text{k}) \), \( B \) = material parameter describing the slope of resistivity vs temperature.

Thermistors are available with different resistance ranges from almost as low as 10 ohm to several thousands of ohms. They are available as discs, pointed glass encased probes, with different current capacities. Normally termistors do operate in the temperature range of \(-40^\circ \text{C}\) to \(+150^\circ \text{C}\). There are termistors with wider temperature ranges also.

2.3.1 LINEARISATION OF THERMISTOR

Linearisation of thermistor is needed for (1) making the calibration easier and (2) making direct measurements in their final engineering units from LCD/LED digital meters.

The thermistor response can be linearised within certain limitations of range by shunting the thermistor
with an appropriate resistance based on the characteristics of the thermistor as well as the required range of measurement.

If $R_1$, $R_2$, $R_3$ .... are the resistance of the thermistor at temperatures $t_1$, $t_2$, $t_3$ .... respectively, the effective resistance after shunting with a resistance $R$ are obtained as $r_1$, $r_2$, $r_3$ .... etc. as given by the relation

$$\frac{1}{R_1} + \frac{1}{R} = \frac{1}{r_1}$$

i.e $r_1 = \frac{R \cdot R_1}{R + R_1}$ and

$$r_2 = \frac{R \cdot R_2}{R + R_2}$$

The value of $R$ is so chosen that $r_1$, $r_2$, $r_3$ .... are linearly inversely proportional to temperature. It can be seen that the percentage of non-linearity increases for larger ranges of temperatures. But for oceanographic purposes, large ranges are not needed and the linearity is obtained quite satisfactorily in the range of 20°C to 35°C with an accuracy of ±0.5°C.

The Fig. 7 gives curves with and without shunt resistors. The lower values of shunt resistors lowers the effective resistance also. Suitable series resistors are added to them so that they come within the required ranges.
FIG 7 THERMISTOR CHARACTERISTICS
Polythene tube
Araldite sealing
Stainless steel tube, 1 mm thick.
2-core cable
Thermistor
Transformer oil

Thermistor as cd in case
of electrical resistances needed by the associated electronic circuits.

The thermistor is selected such that its resistance along with the shunt resistance and series resistance comes within the required range already decided, i.e. approximately 50 ohms for a temperature variation of 20°C to 35°C and an effective resistance below 470 ohms. As shown in Fig. 8 the thermistor was encased in stainless steel case for enabling it to withstand the hydrostatic pressure and the contact with sea water.

2.3.2 RESPONSE TIME

Maximum response is obtained by using very thin walled chamber for encasing the thermistor and filling the inner space with transformer oil. The response time of the thermistor probe was studied in laboratory by noting the time needed for attaining the temperature when the thermistor probe is transferred from a high temperature bath to a low temperature bath and vice versa. The graphs given in the Fig. 9 were plotted automatically by a recorder, thus eliminating all the manual errors. The Fig. 9 shows 2 curves plotted by the recorder, A-open thermistor without case, B - encased thermistor with transformer oil.

The curves show that the response time of the thermistor is increased adversely when it is encased in stainless steel case. However the increased response time has
THE GRAPH SHOWS THE TEMPERATURE RESPONSE OF THERMISTOR PROBE -
GRAPH PLOTTED BY A RECORDER.

Speed $\rightarrow$ 5 cms/minute.

Time $\rightarrow$

- Fully exposed
- Encased in S.S. cover filled with oil.
not affected the equipment adversely, since 2 minutes time can be allowed for temperature measurements without any problem.

### FEATURES OF THE THERMISTOR PROBE

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Dimensions</strong></td>
<td>60 mm length, 9 mm dia.</td>
</tr>
<tr>
<td><strong>2. Case</strong></td>
<td>Stainless steel tube with</td>
</tr>
<tr>
<td></td>
<td>60 mm length,</td>
</tr>
<tr>
<td></td>
<td>7 mm l.D.</td>
</tr>
<tr>
<td></td>
<td>9 mm O.D.</td>
</tr>
<tr>
<td><strong>3. Filling liquid</strong></td>
<td>Transformer oil</td>
</tr>
<tr>
<td><strong>4. Resistance variation</strong></td>
<td>200 ohm to 320 ohms corresponding to 20°C to 34°C</td>
</tr>
<tr>
<td></td>
<td>without the shunt resistance</td>
</tr>
<tr>
<td></td>
<td>390 ohms</td>
</tr>
<tr>
<td><strong>5. Response time</strong></td>
<td>less than 15 sec. for</td>
</tr>
<tr>
<td></td>
<td>temperature variations from</td>
</tr>
<tr>
<td></td>
<td>21°C to 34°C without encasing.</td>
</tr>
<tr>
<td></td>
<td>About 60 sec. for</td>
</tr>
<tr>
<td></td>
<td>temperature variation between</td>
</tr>
<tr>
<td></td>
<td>22°C to 31°C with stainless</td>
</tr>
<tr>
<td></td>
<td>steel encasing and transformer oil filling.</td>
</tr>
<tr>
<td><strong>6. Capacity to withstand</strong></td>
<td>tested up to 30 kg/cm² with</td>
</tr>
<tr>
<td>pressure</td>
<td>no adverse results.</td>
</tr>
</tbody>
</table>
2.4 SALINITY CELL

The resistance of any conductor varies directly as its length (L cm) and inversely as its area (a sq. cm); that is

\[ R = \frac{\rho L}{a} \text{ ohm} \]

where \( \rho \) is a constant, the specific conductance or resistivity of the conducting material. The specific conductance designated by \( K \), of a given material is defined as \( \frac{1}{\rho} \text{ ohms}^{-1} \text{ cm}^{-1} \), hence may be written as

\[ R = \frac{1}{K}a \]

This relation shows that for obtaining higher values of \( R \), the salinity cell should be long with very low cross-sectional area. Considering the practical limitations and the equivalent resistance requirements of the complete electronic system, the length of the cell is taken to be 2.5 cms, with a cross-sectional diameter of 8 mm as shown in Fig.10. Two platinum electrodes of .5 x 1 sq. cm, area were used for passing electricity to the solution. This has resulted in an equivalent resistance of about 150 ohms corresponding to 35 salinity at 30°C. This matches well with the other sensors in the system. The extra lengths of 7 cms, each provided on either sides of the cell reduces the conductance through the outer path to the minimum.

2.4.1 SHUNTING OF SALINITY CELL

As per the system design adopted, the electrical
FIG. 10 CROSS SECTION OF SALINITY CELL

Dimensions : mms.
resistance of the cell is the basic criterion which has to be limited within certain range as per its requirements. Similar to thermistor probe, salinity probe also undergoes variations in electrical resistance universally proportional to salinity at constant temperature as given in the graph in Fig.11. It varies from infinity to approx. 150 ohm corresponding to 0 to 35 salinity at 30°C. This wide variation cannot be accommodated in the system which has been planned. Hence the cell is shunted with an appropriate resistance so that its effective resistance comes within the required range. The shunting has further helped to reduce the non-linearity of the cell characteristics, as given in Fig.12, though it could not make it fully linear unlike the thermistor sensor.

2.4.2 BOUNDARY EFFECTS

The cell conducts through the shortest distance between the electrodes as well as through a wider path outside the cell. The presence of conducting materials affect this external path. Similarly the insufficient area around the probe also affects the conductivity of this path. Experiments were conducted to find out these limits.

It has been noticed that the characteristics of the cell has not been affected when stray conducting materials such as a metal plate or rod remain more than 50 mm away from the sensor.
Figure II: Salinity vs. Resistance of Cell.
2.4.3 POLARISATION EFFECT ON THE CELL

The cell terminals undergo polarisation, as they are subjected to electrolysis. During electrolysis Hydrogen and Oxygen are released and their bubbles are formed on the electrode restricting the easy passage of electrons. This gradually increases the resistance of the electrical path. This can be reduced by removing the bubbles mechanically. But the most satisfactory method of overcoming polarisation is to employ a rapidly alternating current of low intensity. The direction of the current is reversed a thousand times per sec. and the polarisation produced by each pulse of the current in one direction is neutralised by the next in the opposite direction.

2.4.4 EFFECT OF TEMPERATURE ON SALINITY CELL

The conductivity of sea water increases with temperature. Salinity is a constant for given sea water even at different temperatures. But conductivity is different at different temperatures.

The equivalent conductance at infinite dilutions increases with increasing temperature as described by Samuel Gbadstone (1940) and a formula of the type

\[ A_t = A_{25} (1 + x) (t - 25) \]

is applicable where \( A_t \) and \( A_{25} \) are the values at \( t \)° and 25° respectively, as \( x \) is a constant for each electrolyte. For salts \( x \) is about 0.019 to 0.021, so that the
FIG. 12. Relation between salinity and electrical resistance.

ELECTRICAL RESISTANCE - Ohm.
equivalent conductance at infinite dilution at ordinary temperature increases by about 1.92 to 2.2 per degree.

The results described apply particularly to infinite dilution. But similar conclusion holds for strong electrolytes at appreciable concentrations.

When conductivity increases with temperatures, electrical resistance decreases. The exact nature of variations in electrical resistance is needed for making corrections for the temperature effect on salinity readings. The graphs in Fig. 12 shows how the effective electrical resistance of the salinity cell varies with temperature at different values of salinity. The graphs show that the temperature effect on the cell is near to zero at zero salinity. The effect is higher at higher values of salinity and the resistance of the cell decreases with increase in temperature at a given salinity value.

The salinity sensor can withstand any reasonable hydrostatic pressure as its inter space is filled with araldite and made solid with no air gap.

2.4.5 FEATURES OF SALINITY CELL

The relevant features of the cell are as follows:

1. Electrical resistance $\rightarrow$ infinity to 150 ohm as the salinity varies from 0 to 35 PPT at 30°C without shunting (varies up to ±5% for different pieces)
2. Electrical resistance as the salinity varies from 0 to 35 PPT at 30°C by shunting with 100 ohms ...

3. Distance between terminals 70 mm

4. Length of cell 210 mm

5. Diameter of glass tube 8 mm

6. Thickness of glass tube 1 mm

7. Inside diameter of outer PVC tube 20 mm

8. Outside diameter of PVC tube 25 mm

9. Filling material araldite

10. Minimum water level needed above and below the cell 5 mm

11. Maximum distance where conducting materials do not affect the cell 10 cms.

2.5 DEPTH SENSOR

The depth sensor developed for the system consists of a stainless steel bellows whose expansion is a function of hydrostatic pressure acted upon it from inside. The expansion of the bellows is converted to inductance of an electrical coil. The inductance variation of the coil is taken as the measure of the depth to which the sensor is exposed.
2.5.1. DESIGN OF BELLOWS

The pressure rating of the bellows depends on their physical dimensions and the characteristics of the materials with which the bellows are made. Bellows are made out of stainless steel and in special cases out of Nickel, Berilium copper etc. The pressure can be applied either from outside or inside as needed. The squirm pressure of an internally pressurised bellows is given by

\[ P_s = \frac{2\pi K}{L} \]

where \( K \) is the overall spring rate and \( L \) is the maximum working length. A more conservative formula allowing for some eccentricity tolerance is

\[ P_s = 5.02 \left( \frac{K \times \text{ID}}{\text{OD} \times L} \right) \]

where ID and OD are the inside and outside diameters of the bellows. The design details of one of the bellows made by M/S Servometer Corporation as per the specific needs of the case are given in Fig.38

The life of a bellows is expected between 5000 and 10,000 cycles of operation. These bellows manufactured by Servometer Corporation is very precise and unique, based on the new electrodeposition technique for obtaining uniform wall thickness. As shown in Fig.13, the bellows is encased in a stainless steel tubes with further protective covering with flexible neoprene hose for easy transmission of pressure. The ferrite rod mounted on the tip of the bellows
FIG. 13  CROSS SECTION OF
DEPTH TRANSDUCER

DIMENSIONS: mm.
moves along with the contraction of the bellows. This rod acts as the plunger core of an electrical coil thereby altering its electrical inductance.

2.5.2 ELECTRICAL COIL OF TRANSDUCER

The electrical coil produces inductance variations proportional to the position of the plunger core inside the coil.

The length and diameter of the coil is already fixed based on the property of the bellows and the space available. Since the bellows moves about 4 mm corresponding to about 100 m depth, the length of coil is decided to be more than 3 times more in order to avoid the non-linear end portions as shown in Fig.14, which is explained in detail below.

2.5.2.1 DESIGN OF THE COIL

The basic features of the coil needed are:

1. Dimensions should match with the bellows movements i.e. 4-5 mm for 100 m depth.

2. The impedance should match with the common signal conditioner, i.e. about 50 ohms variation below 470 ohm at 1000 Hz.

3. The nature of inductance variation should be similar to that of salinity and temperature, i.e. inversely proportional to the depth.

4. Inside diameter of coil: 8 mm (for accommodating a core of 4 mm dia)
The inductance of the coil with air core is given by

\[ L = \frac{4 \pi N^2 A}{L} \times 10^{-9} \text{ Henries} \]

where \( N \) = no. of turns, \( A \) = area of cross section of coil and \( L \) = length coil.

If the solenoid contains a rod of iron of constant permeability \( \mu \) and of the same cross sectional area as that of solenoid

\[ L = \frac{4 \pi N^2 A \mu}{L} \times 10^{-9} \text{ Henries} \]

Under the decided values of the dimensions of the coil, namely,

- I.D. .. 8 mm
- O.D. between 9 and 15 mm
- Length .. 25 mm
- Gauge of wire .. 42 SWG
- Diameter of core .. 4 mm

The number of turns of coil was estimated to be 2500

2.5.2.2 RESPONSE OF COIL ON CORE MOVEMENTS

The formula above gives the inductance and thus the impedance of the coil in the presence of the core movements on an ideal condition. But the coil parameters deviate from the ideal condition at the ends of the coil. The exact nature of the impedance at the ends is seen in the graph in Fig.14 after conditioning the signal.
Figure 14: RESPONSE OF CORE POSITION AND OUTPUT VOLTAGE OF OPAMP.
The graph shows that towards the ends of the coil, the response is non-linear. Only about 1/3 of the total length of the coil is linear. This property was studied with coils of different lengths. It was confirmed that for longer coils, this non-linearity is negligible in comparison with its length. In general, about 3 to 6 mm length of the coil on either sides become non-linear due to the end effects. The magnetic flux lines here are curved and the linear relationship is not followed. It was found from the actual measurements that the coil should be at least 20 mm in order to avoid the end effects properly.

2.5.2.3 FABRICATION OF THE COIL

The actual fabrication of the coil is very important as it has to work at very hazardous environment. The coil should have the following properties.

1. Capacity to withstand high hydrostatic pressure.
2. No effect on saline water in the long run.
4. No electrical leakage in the presence of the highly conductive sea water.

In order to achieve the above properties, the coil was moulded in nylon with araldite as the sealing agent. It was found that under this condition the coil could withstand hydrostatic pressure even much above the required limit. After deciding the features of the bellows, the
coil and the core, the final dimensions were decided and fabricated as in Fig.13 which shows the cross section with all details and without the final neoprene cover.

### 2.5.2.4 THE FEATURES OF THE DEPTH SENSOR

Four types of depth sensors using three different types of bellows of types SK—8180A, SK—8180B, SK—8180C and 9519 were constructed, with the features given below:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Range</td>
<td>30 m, 100 m and 200 m</td>
<td></td>
</tr>
<tr>
<td>2. Length</td>
<td>160 mm</td>
<td></td>
</tr>
<tr>
<td>3. Diameter</td>
<td>25 mm</td>
<td></td>
</tr>
<tr>
<td>5. Length of coil</td>
<td>25 mm</td>
<td></td>
</tr>
<tr>
<td>6. L.D. of coil</td>
<td>8 mm</td>
<td></td>
</tr>
<tr>
<td>7. Thickness of core</td>
<td>4 mm</td>
<td></td>
</tr>
<tr>
<td>8. No. of turns of coil</td>
<td>2500 turns of 42 SWG copper enameled wire</td>
<td></td>
</tr>
<tr>
<td>9. Inductance variation of the sensor:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) 30 m depth</td>
<td>38.5 mH to 29.7 mH</td>
<td></td>
</tr>
<tr>
<td>b) 100 m depth</td>
<td>37.7 mH to 29.3 mH</td>
<td></td>
</tr>
<tr>
<td>c) 200 m depth</td>
<td>37.9 mH to 29.2 mH</td>
<td></td>
</tr>
<tr>
<td>10. Coil excitation</td>
<td>1000 Hz sinusoidal waves at 5V P.P.</td>
<td></td>
</tr>
</tbody>
</table>
11. Pressure Coil was moulded in nylon protection with araldite sealing

2.5.2.5 AMBIENT TEMPERATURE EFFECTS ON THE COIL

The ohmic resistance of coil varies proportional to its temperature. Even though the coil is concealed inside the steel case, it will slowly pick up the ambient temperature and change its electrical resistance which will directly reflect on the readings proportionally. If this error is not eliminated, the depth readings will have to be corrected according to the temperature changes of the water similar to that done for salinity measurement. But this error is comparatively low and is proportional to the temperature. Therefore this can be fully eliminated. The resistance variation of the coil was studied with the help of a hot oven and the graph was plotted. These proportional changes in resistance was opposed with that of a thermistor which has got resistance characteristics inversely proportional to the temperature. The thermistor was shunted with an appropriate resistance so that its effective resistance variation is exactly equal to that of the coil, but in opposite direction. The Fig.15 gives both the curves which are sufficiently linear. As the hot oven could not be maintained at critical temperatures the values could not be taken precisely.

The thermistor with its shunt resistance was connected in series to the coil and the experiment was repeated.
The effect of temperature on (A) coil, (B) shunted thermistor, and (C) the combination of A and B in series. Y-axis of C is given as $Y_1 + Y_2$.
The ambient temperature effect, as shown in the third curve, is found fully eliminated.

2.6 UNIFORM SIGNAL OUTPUTS FROM SENSORS

In order to make the complete system simpler, highly portable with easy and reliable operation, the signals from sensors must have uniform signal output. This has been achieved fully in the case of sensors of salinity, temperature and depth. Though the signals from current and current direction are different in nature they are quite strong so that they could be displayed without much problems.

2.6.1 UNIFORM FEATURES OF SENSORS

The following are relevant features of the sensors which have made them accommodative to the composite instrument system.

2.6.1.1 SENSOR OUTPUTS

<table>
<thead>
<tr>
<th>Signal output</th>
<th>Range of resistance/impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>220 ohm to 180 ohm, diff. 40 ohm</td>
</tr>
<tr>
<td>Depth</td>
<td>200 ohm to 150 ohm, diff. 50 ohm</td>
</tr>
<tr>
<td>Current</td>
<td>450 to 462 ohm, diff. 12 ohm for rotor-electric induction. 12 ohm pulses of 0 to 17.7 Hz corresponding to 0 to 400 cms/sec. speed. 'ON-OFF' pulses of 6V for magnetic induction</td>
</tr>
<tr>
<td>Current direction</td>
<td>0 to 2000 ohms</td>
</tr>
<tr>
<td>Salinity</td>
<td>100 ohm to 60 ohm</td>
</tr>
</tbody>
</table>
2.6.1.2 OPERATIONAL SUPPLY VOLTAGE

Salinity          ... Excitation by A.C. bridge at 5V
Temperature      ... Excitation by A.C. bridge at 5V
Depth            ... Excitation by A.C. bridge at 5V
Current          ... Excitation by A.C. bridge at 5V
Current direction ... Excitation by D.C. bridge at 6V

2.6.1.3 SIGNAL TRANSMISSION

Salinity          ... 2-core unshielded cable
Temperature      ... 2-core unshielded cable
Depth            ... 2-core unshielded cable
Current          ... 2-core unshielded cable
Current direction ... 3-core unshielded cable
                     (one core used for clamping the stylus)

2.7 MULTIPLEXER

The function of the multiplexer in the system is to give connections to the different sensors in time, one by one, so that the sensors come in the circuit one by one and their respective informations are displayed in the display meters, one by one.

The essential features needed for the multiplexers here are:

1. Contact resistance should be extremely low — below .1 ohm

2. Both a.c. and d.c current should be allowed to pass though the multiplexer switching contacts.
3. Should be very compact, as this has to be accommodated inside the underwater probe. Should not take more than 100 c.c. space.

4. Should operate on 9V with very low current consumption.

5. Should be very rugged as it has to withstand all the shock and vibration of the remotely operated underwater probe.

6. Facility for remote operation.

There are quite some multiplexers available in the market using integrated circuits belonging to both analogous as well as digital types as described in the Data Acquisition Handbook (1978) of National Semiconductor Corporation.

All of these multiplexers shown above have high contact resistances above 150 ohms, as these are used for multiplexing after signal conditioning, engaging different signal conditioners for each sensor. Since the aim of this work is to make the remotely operated underwater probe very compact, rugged and small with minimum electronics and power consumption, not even one signal conditioner can be kept inside the underwater unit. Therefore multiplexer has to be engaged prior to signal conditioning where contact resistances of the order of fractions of ohms are significant. The whole success of this method of remote operated data acquisition depends very much on the extremely low
contact resistance of the multiplexer. There is no suitable multiplexer available in the market with the above features. Hence this task was taken up and four different types were developed as given below:

2.7.1 MUX-100

I.C. timer multiplexer MUX-100 is a multiplexer control system for accomplishing the required switching function as shown in Fig.16. Before connecting the power from the onboard supply, the terminal remains closed. This terminal is used to connect the 'current sensor' which requires an independant and long time. When the power is switched on, the normally closed relay used for connecting current sensor remains opened disconnecting the sensor. The timer 555 integrated circuit oscillates at 8 seconds 'on' and 2 sec. 'off'. The output of this timer is connected to a CMOS counter integrated circuit 4017 which under the given circuit configuration changes its output levels from low to high, one by one, corresponding to each pulse from the 555 timer. The process is repeated indefinitely until the power is 'off'. 4017 counter has got 10 outputs and the system needs only 4 outputs for engaging 5 sensors and one energising coil which has to work in parallel to the direction sensor. One sensor (current) is got connected when the power is disconnected to the under water unit. Hence only 4 outputs are needed. The first four outputs are amplified
using transistors CIL 513 and connected to 4 Nos. reed relays. The number of relays are switched on one by one according to the generation of positive pulses in the timer 555. The current direction sensor needs 2 contacts independently, one for connecting to the potentiometer resistance and the other for actuating the coil of the compass. Hence the first output is used to operate 2 reed relays through 2 independent amplifiers as given in the circuit.

Now the timer takes $8 + 2 + 8 + 8 + 8 + 2 + 8 = 38$ secs. for scanning the four sensors one by one. If the power is not switched off after 38 secs., the 5th, 6th etc. outputs also will be activated. This will lead to confusion. Another time controlled relay in the onboard display unit switches off the complete system after 48 secs. The last 10 secs. is used to display a 'reference' signal. (Please see the operation of the equipment for more details).

The multiplexer MUX-100 has met all the requirements needed for the system. As it has got gold plated reed relay contacts, the contact resistances are extremely low—below 50 milli ohms. Being reed switches, they do not create problems of vibration. MUX-100 scans the sensors in a given sequence. The change from one sensor to another is indicated by an alarm signal produced during the 2 secs. 'off' time which reminds the operator that it is time to switch over the sensor to the next one. The multiplexer system is
found to work quite reliably without a single failure. But 10 secs. interval is needed between two operations.

2.7.2 MUX-110

As shown in Fig.17, MUX-110 also uses one counter I.C. 4017 for switching on reed relays one by one. Here instead of the relays are switched on automatically using the pulses generated from a built-in astable multivibrator. The required command pulses are generated and sent manually at required times from the on-board unit. Therefore the multiplexer operation is always at our control. As shown in Fig.17 when the power is switched on, 4017 is 'on' with its 1st output in high state. The +ve power line to the under water unit is switched 'off' for a short duration of .2 to 2 secs. This switches off part of the electronics including the amplifier and the relays. But the 4017 counter and its associated parts do not go off since sufficient energy is stored in the 500 MFD condenser which keeps the counter alive even when the power is off. The diode does not allow this charge to be distributed to other parts during the 'off' time. This 'off' signal results in a -ve signal at the base of PNP transistor 222. Therefore the PNP transistor conducts during this -ve input producing a +ve signal to the input of 4017 counter. The counter after obtaining a pulse in its input, changes its output to the next position. This process is repeated for every 'switch off' action in
the 'onboard' unit of the instrument.

This method is also found to be quite reliable. It has got the advantage over the MUX-100 that the sensor can be selected as and when needed by pressing a switch. The disadvantage is that there is an uncertainty about the starting sensor. Because the charge stored in the circuit does not allow the first output to be set on every time unless enough long duration is given to discharge it completely. That means, more than 2 minutes has to be allowed between 2 operations.

2.7.3 MUX-120

MUX-120 is a mechanical type multiplexer engaging a reduction gear motor and read switches activated by the magnet mounted on a rotating arm connected to motor. As shown in Fig.18 the shaft of the motor working on 6V is connected to a worm wheel, the rotation of which is further stepped down in decade. The handle takes step-wise positions in its rotatory motion. During one complete rotation, it takes 10 positions. One magnet is mounted on the arm and 10 sensitive reed switches were fixed close to the 10 positions such that each reed switch turns from its normally opened condition to closed condition. In this condition 10 sensors can be connected. But as there are only 5 sensors, and only 4 additional contacts are needed, 4 pairs of opposite sensors are connected in parallel. 2 Nos.
Pairs of parallel connections from 5 x 2 nos. reed switches activated by magnet.

FIG 18 REMOTE OPERATED MULTIPLEXER - MUX - 120
magnets were used and both the switches in the pairs were activated. This has further ensured the operation of switches. In the second place (i.e. current direction) the two switches are used separately for connecting potentiometer sensor and its energising coil.

This multiplexer also is found to be quite dependable. It takes current only for a very short duration of 2 seconds when the motor works for changing position from one sensor to another. The rest of the time it does not take any current unlike other types explained earlier.

2.7.4 MUX-130

This multiplexer engages a new generation integrated circuit LM3914 from National semiconductor, U.S.A. The I.C. has 10 outputs. When voltage is applied to its input, either one of the ten outputs goes 'low' while all others remain 'high'. Any required output terminal can be brought to 'low' by feeding the appropriate voltage to its input. The outputs are connected to reed relays after amplification. Here also, since only 4 outputs are needed, as shown in Fig.19, two consecutive outputs are joined. The required input voltages are set in the 'onboard' meter and connected to the 'under water unit' through the long cable by means another pole of the same selector switch. One advantage of MUX-130 is that any sensor can be selected at any time, while in others, they can appear only in the particular
sequence. The disadvantage is that 4-core cable is needed to operate the underwater probe as against 3-core needed in all other cases. Because, one extra line is needed for applying the required input voltage to the LM3914, as shown in Fig. 19.

The Fig. 20 shows the time sharing of the multiplexers MUX-100, 110, 120 and 130. Here in all cases \( t_1 \) the time taken for current measurement is independent of multiplexer operations. \( t_2 \) is any interval time after current measurement, which is common in all cases. \( t_3, t_4, t_5 \& t_6 \) are the times for current direction, depth, temperature and salinity. These follow in sequence in MUX-100, 110 and 120. But in 130, the sensors can be selected in any order. In MUX-100, the times given are constant and in all other cases, they can be altered as needed.

The chart below gives the comparative features of the four multiplexers.
Start

Auto off Start

MUX-100
Current 30 sec

MUX-110
Water current 30 sec

MUX-120
Water current 30 sec

MUX-130
Water current 30 sec

$1$ for current for all MPXS

$2$ Any interval of time.

$3, 4, 5, 6, 7$

Fixed times respectively for current direction, temp., salinity, depth and reference.

$3, 4, 5, 6, 7$

Any required times for 10, 120 and 130

--- do ---

--- do ---

FIG-20 TIME SHARING CHART OF MULTIPLEXERS
## 2.7.5 Comparative Features of the Four Multiplexers

<table>
<thead>
<tr>
<th>Feature</th>
<th>MUX-100</th>
<th>MUX-110</th>
<th>MUX-120</th>
<th>MUX-130</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Space needed</td>
<td>100x50x20 mm</td>
<td>100x50x20 mm</td>
<td>60 diax50 mm</td>
<td>100x50x20 mm</td>
</tr>
<tr>
<td>2. No. of core needed for the cable</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3. Current consumption</td>
<td>60 mA constant</td>
<td>60 mA constant</td>
<td>100 mA for 2 sec. and 0 for the rest</td>
<td>60 mA constant</td>
</tr>
<tr>
<td>5. Reliability</td>
<td>Good</td>
<td>Good</td>
<td>Good, but should be more careful</td>
<td>Good</td>
</tr>
<tr>
<td>6. Interval between two operations</td>
<td>Minimum 10 seconds</td>
<td>Minimum 2 minutes</td>
<td>No restrictions</td>
<td>No restrictions</td>
</tr>
</tbody>
</table>
2.8 SINGLE 3-CORE or 4-CORE CABLE FOR TRANSMISSION OF 5 PARAMETERS FROM THE UNDER WATER PROBE

It is one of the specific aims of the project to reduce the number of cable used for operating different instruments under water for the benefit of convenience in handling as well as simultaneous data collection. Though a multicore cable with enough cores independantly for every sensor can solve the problem, the use of such a cable is quite undesirable for operation in rough sea conditions as its comparatively thin cores and their insulations are likely to be damaged easily during the operations. Moreover, the handling of such cable will be quite tiresome. The aim of reducing the number of core to 3 or 4 is to make the operation easy. Further, such cable with 3-core or 4-core are plenty available in the market and their selection and procurement will not be of any problem.

The number of core is reduced to 3 for operating the complete system and 4 in the case of MUX-130. It can be reduced to 2 also by incorporating the signal conditioner, A/D converter and transmitting the signals super imposing on the supply line. This will make the under water probe to be heavy, bulky, complicated along with much power consumption. This will spoil the very aim of developing a reliable acquisition system of easy and convenient operation. The very basic philosophy of such remote operated data acquisition systems is that the remotely operated
sensor probe should be most rugged, simple with minimum electronics and controls so that it is subjected to minimum complaints. Thus the present number of the core i.e. 3 in the case of MUX-100, 110 and 120 and 4 in the case of 130, is the result of a compromise between the essential requirements and operational problems.

The cores of the cable are engaged as follows:

1. +ve supply line
2. -ve supply line
3. signal carrying line and
4. multiplexer control line (in the case of MUX-130)

The third core carries the signal from the sensors one by one. There are no stringent specifications for this 3-core and 4-core cable.

2.8.1 THE FEATURES OF THE CABLE

The requirements of this cable are very liberal, as given below:

1. Voltage .. Above 9V
2. Current .. 200 mA max.
3. Insulation Suitable for 20V
4. Sheathing 
   .. Normally PVC, preferably neoprene for better durability
5. Breaking strength
   .. Normally 100 kgs., preferably above 200 kgs so that the necessity of additional wire
rope or plastic rope for supporting the weight and hydrodynamic drag of the under water unit can be avoided.

6. Pliability .. very high
7. Diameter About 10 mm
8. Shielding Not needed
9. Armouring Not needed. This will reduce the pliability of the cable.
10. Material of core tinned copper
11. Core size .. Approx. 40/.2/3 or 40/.2/4
12. Electrical resistance .. Less than 10 ohms for 100 m length

Even though it needs only maximum 9V at maximum 200 mA, this cable can handle 440V at 15 Amps. The end connections and joins have been made strong so that the equipment can be operated in the most hazardous environments safely and covers the standards stipulated for hazardous environments.

2.9 SIGNAL TRANSMISSION

The signal is transmitted from the under water probe to its display console on-board the vessel through the cable. Only the -ve supply line and one of the cores
(other than the +ve supply line) comes in the circuit loop of the sensors. Since the signals are not conditioned before transmission, the properties of the cable affect the signal during the transmission up to certain level.

2.9.1 THE RELEVANT PROPERTIES OF THE SIGNAL

2.9.1.1 THE FREQUENCY OF THE A.C. SIGNAL

The a.c. waves passed through a cable undergoes attenuation in relation to frequency. For higher frequencies, attenuation also is high. The frequency of a.c. signal in the system under report is limited to 1000 Hz where the attenuation is found to be low.

2.9.1.2 SHAPE OF THE A.C. SIGNAL

The shape of the a.c. signal undergoes distortion while passed through cable. This distortion depends upon the capacitance and inductance associated with the circuit 100p. The distortion is least or minimum for sinusoidal waves. Hence sinusoidal waves were used as signal carriers in the system.

2.9.1.3 VOLTAGE OF THE A.C. SIGNAL

High voltage signal will undergo attenuation due to insulation breakdown. Since the voltage of any of the signals does not exceed 9V, there is no such problem.

2.9.1.4 IMPEDANCE OF SIGNAL

This is a very important factor which affects
(other than the +ve supply line) comes in the circuit loop of the sensors. Since the signals are not conditioned before transmission, the properties of the cable affect the signal during the transmission up to certain level.

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2.9.1.4 IMPEDANCE OF SIGNAL

This is a very important factor which affects
seriously all types of sensors and instrumentation especially those of remote operated types. If the impedance of the signal is high, noise in the surroundings will penetrate into the system and the system will fail to provide reliable data. The system will need very complicated and expensive noise eliminating methods. As the impedance is lower, the system is more and more immune to noise problems. The speciality of the system under report is that all the sensors are at very low impedance so that they are highly immune to noise and no special efforts are needed to protect them from noise. Not even the minimum standard precaution of using shielded cable is needed in the system for noise elimination.

2.9.2 THE PROPERTIES OF CABLE IN RELATION TO SIGNAL TRANSMISSION

2.9.2.1 OHMIC RESISTANCE OF THE CABLE

The ohmic resistance of the cable adds to the series resistance of the sensor in the Wheatston bridge network. This resistance is quite low for 500 metres of cable and it can be accommodated in the bridge. Any alteration in small values of cable can be adjusted in the series 'zero set' provision given in the electronic circuit. The sensors are calibrated with the complete length of cable and their ohmic resistances are also included here.
2.9.2.2 CAPACITANCE OF THE CABLE

Cable has got a capacitance formed by the long conducting cores and the insulation as the dielectric material. The cable having uniform structure throughout its length, the capacitance is proportional to its length. The capacitance of cable affects the performance of sensors differently.

The capacitance shifts the signal level of sensors with pure ohmic resistances, i.e. thermistor, current direction and salinity. Since the calibration is done with the long cable, this is got rid of and any effects due to the alterations in the length of cable can be eliminated by precisely adjusting the presets given in series to the sensors. The effect of capacitance on the other sensor of current direction is insignificant as its signal level variation is much higher, i.e. from 0 to 2000 ohms. Its effect on the current sensors do not cause any problems as the rotations of the rotors are detected digitally. The effect of capacitance on thermistor is given in the Fig. 21. The shifts caused can be fully eliminated by calibrating the instrument with its cable.

The effect of capacitance on sensors with reactive resistance is much complex. The capacitance virtually forms a tank circuit with the coil in the sensor. The capacitance may cause even resonance to the sensor coil.
FIG 21 EFFECT OF CAPACITANCE ON THERMISTER IN THE CIRCUIT
One important conclusion derived from the above analysis is that the coils of sensors should be designed such that they never come near to resonant levels. Because the signal output goes non-linear around the resonance levels. Resonance being a function of the frequency of excitation as given in the expression \( f = \frac{1}{\frac{2\pi}{\sqrt{LC}}} \), the frequency of excitation \( f \) of the sensor, the inductance \( L \) of the sensors and the capacitance \( C \) of the cable should be selected to avoid this unwanted region.

The transducers are designed to have reactive sensor elements having impedance in the range 20 to 40 mH, which when excited with 1000 Hz. sinusoidal waves give impedance variations from approx. 120 ohm to 240 ohms. This goes well matched with other sensors with ohmic resistance of the system (except current and current direction which are separately treated) as per the design requirements. Under this condition the sensor coil with the capacitance of 500 m cable are far away from resonance level. The capacitance needed for resonance should be above 4 MFD (equivalent to approx. 1000 meters of cable) for making resonance. It is clear from the mathematical analysis as well as the practical measurements from the laboratory experiments that the signal level of sensor is raised in the presence of capacitance as seen in Fig.22.
The graph shows how the shunt resistance and series resistance eliminate the effect of capacitance and lateral shift.

Transducer

Lateral shift is eliminated adjusting the resistance $R_4$. 

$C = 0$, $C = 0.2$ MFD, $C = 0.2$ MFD shunted with resistance $R_3$. 

FIG 22

Movement of core —— mms
The graph shows how the shunt resistance and series resistance eliminate the effect of capacitance and lateral shift.

- Lateral shift is eliminated by adjusting the resistance $R_4$.

- $C = 0$
- $C = 2$ MFD
- $C = 2$ MFD shunted with resistance $R_3$
2.9.2.3 INSULATION RESISTANCE OF CABLE

The insulation resistance of the cable is associated with leakage problems. High insulation resistance is needed for signals with high impedances. Since the impedance of the signals here are very low, this question does not arise. Moreover, as the signal impedance is extremely low even slight damages of the cable due to water leakage at high pressures will not create detectable errors.

2.9.2.4 DIELECTRIC CONSTANT OF INSULATING MATERIAL

The values of this property of insulating material directly affects the capacitance of the cable whose affects have been already analysed above. The dielectric constant affects the capacitance as given:

\[ C = \frac{KA}{4\pi d} \]

where \( K \) is the dielectric constant, \( A \) is area of capacitor (proportional to the length of cable) and \( d \) is the distance between the plates (i.e., core).