CHAPTER - 5
DEVELOPMENT OF MUTUAL INDUCTANCE TYPE SODIUM LEVEL SENSOR WITH A NEW TEMPERATURE COMPENSATION TECHNIQUE

5.1 INTRODUCTION

The under sodium ultrasonic viewing system efficiently functions only if the components are adequately immersed in sodium pool. This is ensured using level measuring system. Even though the traditional continuous level sensors used in small experimental reactor is also of non contact type working on mutual inductance principle, for large power reactors robust, longer length (~ 10 m) level probes are required. Hence, the third part of the research work is targeted towards development of a long length level probe with application focused towards PFBR. As the temperature gradient is more for longer probes, better temperature compensation technique is required and a new temperature compensation technique has been devised to improve the accuracy which also simplifies the electronics. Detailed developmental activities in sensor, new temperature compensation technique, studies to improve the sensitivity, its electronics and sodium testing results are discussed in this chapter.

As already discussed in chapter-1, the primary and secondary circuits of FBR have a large number of free liquid –sodium surfaces. Control of the relative level is important during various conditions of the reactor operation. Hence, a large number of measurements of high temperature sodium level sensors are required. As an alkali metal, sodium is highly reactive with air and water and it is incompatible with many commonly used engineering materials. In addition to the essential requirement of compatibility of the sensors used with liquid sodium up to 823 K, the integrity of the system should be maintained even in the case of breach of the sensor. So, conventional instrumentation devices cannot be readily used in sodium systems. The above requirements necessitate specially developed sensors for use in
liquid sodium. The characteristics required for level sensors include (i) wide and high operating temperature with simple temperature compensation technique, (ii) should be of noncontact type with minimum weld joints, (iii) should not depend on wetting effects and (iv) should be robust and withstand cross flow during normal operation. Operationally the levels at the pool region and secondary circuit must be measured continuously to find the gross sodium hold up in the primary circuit, to ensure that an adequate level is maintained at the heat exchanger inlet to prevent vortex and gas entrainment and also to monitor entry of secondary sodium into primary sodium. The typical installations of level sensors in PFBR is shown in Fig. 5.1

![Fig. 5.1 Typical Installation of Level sensors in PFBR (LS-Discontinuous level probe, LW-Continuous level probe)](Safety Report on PFBR)
Discontinuous level measurement is needed to guard against any gross loss of coolant from the system. It is used for safety purposes and also provides redundancy. Typical discrete level sensors work on the principle of step change in resistance when sodium touches the sensing portion. The major disadvantages of this system include (i) poor wettability at low temperature (200°C) and (ii) effect of vapor deposition on probe surface. To overcome these problems, noncontact, mutual inductance type discontinuous level sensors are essential.

5.2 THEORY OF LEVEL PROBES

Consider a long solenoid, wound in insulated wire and is surrounded by a liquid metal of high electrical conductivity. If a constant alternating current is passed through the solenoid, the alternating flux produced will induce alternating electro motive forces in the surrounding liquid metal. Schematic of magnetic field lines due to current through the solenoid are shown in Fig. 5.2. Each turn produces circular magnetic field lines near itself. Near the solenoid’s axis, the field lines combine into a net magnetic field that is directed along the axis. The closely spaced field lines there indicate a strong magnetic field. Outside the solenoid, the field lines are widely spaced, where the field is very weak.

Fig. 5.2 Magnetic field lines due to a current through the solenoid

The surrounding liquid metal contributes to this reduction in self inductance. An annulus of liquid sodium of thickness equal to twice the skin depth corresponding to the operating
frequency, is virtually equivalent to an infinite sea of sodium (Mcgonigal, 1971). The change in self inductance is proportional to the depth of immersion. The measurement of self inductance of the coil is hampered by the series resistance of the winding. When the series resistance is high and the self inductance is low, the measurement becomes very difficult and inaccurate. To overcome this, bifilar coil system is used, where the effect may be regarded as change of mutual inductance between the two coils. When alternating constant current is fed into primary coil, e.m.f. induced in the secondary does not depend on resistances of the coils. It depends only on coefficient of coupling and the magnitude of eddy currents produced in the surrounding medium. Change of inductance is caused by eddy currents which produce a magnetic field in opposition to that produced by the primary current in the coil. The penetration of these eddy currents into the surrounding conducting medium is a function of the resistivity of the medium and the frequency of input current. Expressions for mutual inductance (M) and e.m.f induced in secondary coils (e) are given below.

\[ M = \frac{\mu_0 \mu_r N_1 N_2 \pi r^2}{l} \]  

\[ e = -M \frac{dI}{dt} \]  

\[ M = k \sqrt{L_1 L_2} \]

Where  

- \( k \) is the coupling factor, for loosely wounded windings \( k \neq 1 \)  
- \( L_1 \) self inductance of primary coil  
- \( L_2 \) self inductance of secondary coil  
- \( M \) mutual inductance between coils
The induced magnetic vector potential at \((r, z)\) (Nestor, 1979) produced by a driving coil with a fixed alternating current in solenoid coil is given below.

\[
A^{(12)}(r,z) = \frac{\mu_0 I_{n_1} n_2}{\pi (r_2 - r_1)(l_2 - l_1)} \int_0^\infty \frac{1}{\alpha} \left[ I(r_2, r_1) I_1(\alpha r) \sum(\alpha) \right] \left[ \sin \alpha (z-l_1) - \sin \alpha (z-l_2) \right] d\alpha + \frac{\pi}{2} J(r_2, r_1) J_1(\alpha r) \left( 2 - e^{-\alpha (z-l_2)} - e^{-\alpha (z-l_1)} \right) / d\alpha \tag{5.4}
\]

- \(r_1\) Inner radius of coil
- \(r_2\) Outer radius of coil
- \(l_1\) Distance from bottom of coils to \(z = 0\) plane
- \(l_2\) Distance from top of coils to \(z = 0\) plane
- \(l = (l_2 - l_1)\) Coil length
- \(n_1\) Number of primary coil turns
- \(n_2\) Number of secondary coil turns
- \(I_1\) Primary exciting current
- \(\mu_0\) Free space permeability
- \(\alpha\) Separation constant
- \(z\) Transfer impedance
- \(\omega\) Angular frequency of \(I_1\)

Alternating magnetic field produced by current in primary coil along with magnetic field produced by eddy currents generated in surrounding electrically conducting mediums led to generation of e.m.f in secondary coil. E.m.f induced in secondary coil is given below.

\[
V_2 = \frac{j 2\omega m_1 n_2 I_{n_1} \mu_0}{(r_2 - r_1)^2 (l_2 - l_1)} \int_0^\infty \frac{1}{\alpha} \left[ \int \left[ 1 - \cos \alpha (l_2 - l_1) \right] + \pi J^2 (r_2, r_1) \left[ \alpha (l_2 - l_1) + e^{-\alpha (l_2 - l_1)} - 1 \right] \right] d\alpha \tag{5.5}
\]
5.3 **PRINCIPLE OF OPERATION**

The Mutual Inductance type Level Probe (MILP) works on the principle of variation of mutual inductance between two windings when they are in the proximity of an electrically conducting fluid such as sodium. The MILP has two windings wound in bifilar fashion on a non-magnetic stainless steel former. The probe is inserted in a stainless steel pocket. The primary winding of the probe is excited with an AC constant current at a constant frequency. Due to mutual inductance, an electro motive force is induced in the secondary coil. The liquid sodium surrounding the probe acts as a short-circuited winding, because sodium is a good electrical conductor. An electro motive force will be induced in sodium also and the eddy current flows in it. The magnetic flux due to eddy current will oppose the main flux produced by the primary winding. Hence, the net flux linked with secondary decreases and thereby the secondary voltage reduces when the sodium level increases. The secondary voltage is an inverse linear function of the sodium level. When the sodium temperature increases, the resistivity of sodium increases. Hence, the eddy current decreases and the induced voltage in secondary coil increases. So, temperature compensation is required in order to make the output voltage independent of temperature.

5.4 **CONSTRUCTION OF LONG LENGTH LEVEL PROBE**

The sensor consists of sensing element called bobbin and pocket. Traditional level probes R have short active lengths (2.5 m). As long length level probes are required for large power reactors, free insertion and withdrawal of the bobbin into the pocket is required. Therefore, the radial clearance between pocket and bobbin has to be liberal. For the present purpose, a standard pipe of size 1¼” SCH10 (42.16 mm OD, 36.62 mm ID) as pocket and 28 mm diameter bobbin are selected. From the practical point of view, the measurement of the self inductance of a coil is hampered by the series resistance of the windings. To overcome this difficulty bifilar coil system is used.
MILP consists of primary and secondary coils wound in bifilar manner on a stainless steel former of cross-shaped cross section as shown in Fig. 5.3. For the high windings, stainless steel sheathed, Mineral (MgO) Insulated (MI) cable with a copper conductor is used. The primary and secondary coils are wound inside the slots provided in the bobbin. The slots are made in the cross shaped bobbin using Electric Discharge Machining technique. In order to avoid sharp corners in the slot, curved electrodes are used so as to prevent damage to MI cable sheath during winding. Slots are provided up to active length of the probe. The depth of the slot is designed such that the MI cable does not get damaged during installation of the probe into pocket and also during handling.

For the present application, probes of total length of 9.6 m are required. To assess the fabricability of long length level probes, a prototype mutual inductance type continuous level probe of active length 6.0 m and non-active length 3.6 m has been fabricated. The difficulty of fabricating 6 m long sensing element as a single piece, was solved by providing 3 sections, each of 2 m in length. To ensure very low distortion, a welding jig was fabricated to hold the
bend strips in position for laser welding which was also used for joining the 2 m sections to form 6 m bobbin. Special fixtures and a dedicated winding table with rotary holders were fabricated to hold the bobbin while winding the MI cable. For making a long pocket long welding table was fabricated using machined aluminum plate and V blocks. The long tubes were straightened using hydraulic/screw press and finally the straightness of +/- 1 mm per meter was achieved. The robust and long length level probe has been fabricated successfully.

Further, provision has also been made in the pocket to detect the sodium leak using spark plug type leak detector. Leak tight arrangement is achieved using Lip-seal welding, instead of O-ring arrangement due to high temperature. A stainless steel ring with bolt-nut arrangement is used to avoid load on Lip seal welding. To provide biological shielding, SS balls were used instead of stainless steel blocks for free insertion of MI cable as shown in Fig.5.4. In order to provide leak tightness, MI cable is brazed with stainless steel flange using high temperature brazing alloy. For this, a number of mockups have been carried out successfully to study the fabrication feasibility, as the MI cables are fragile and brazing them to stainless steel flange without affecting the thin copper conductor inside posed a major challenge.
PERFORMANCE EVALUATION

The gap between the ID of pocket and OD of bobbin needs to be kept to a minimum to achieve maximum sensitivity. To study the effect of dimensional change in bobbin and the pocket, on sensitivity and temperature coefficient, the prototype probe is tested in sodium at various temperatures ranging from 200°C-550°C. The probe has been tested for full level and zero level over a temperature range of 200°C-550°C in steps of 50°C. The current fed to primary coil is 100 mA and the frequency of this primary current is varied from 2 kHz to 3 kHz in steps of 0.1 kHz in the above temperature range. The secondary voltage and change in primary voltage at different temperatures are obtained at zero and full levels.
Fig. 5.5 % Sensitivity Vs frequency

Using the data a plot is obtained between frequency and % sensitivity (%S) and is shown in Fig. 5.5, where sensitivity is defined by,

\[
%S = \frac{(\text{Zero level secondary voltage} - \text{Full level Secondary voltage}) \times 100}{\text{Zero level Secondary voltage}}
\]

It has been found that 2.5 kHz is the optimum excitation frequency to minimize the effect of temperature on the output. The graph shows a crossover at a particular frequency which is due to variation in flux pattern of sodium surrounding the pocket at higher frequencies. Change in the secondary output voltage due to change in level (zero to full) is around 20% and is sufficient enough to adjust in electronics.

5.6 DEVELOPMENT ON TEMPERATURE COMPENSATION TECHNIQUE

The probe secondary voltage is a function of sodium level as well as temperature. To find out the actual sodium level using MI probe, effect of temperature on secondary output of
the level probe has to be eliminated. The temperature compensation technique is complicated because of the facts, (i) Electrical conductivities of sodium and stainless steel vary with temperature at different rates, (ii) Temperature coefficient for the sensor uncovered and fully covered with sodium is different, (iii) mutual inductance at both the sodium uncovered and fully covered states increases with increasing temperature but at different rates as shown in Fig. 5.6, and (iv) temperature distribution in the direction of length of the probe cannot be determined because it depends on sodium temperature, sodium level, and temperature at the top of the probe and cover gas temperature (Kuniji, 1975).

Fig. 5.6 Electrical conductivities of sodium and stainless steel
Fig. 5.7 Earlier method of temperature compensation

A basic temperature compensation can be achieved by measuring the primary voltage variation, which is a measure of average temperature of the probe. This method of temperature correction achieved through electronics is shown in Fig. 5.7. The procedure for calibration of electronics is, at the lowest operating temperature the electronics is adjusted for zero level and full level by adjusting gain of an amplifier. At the highest operating temperature, only at full level the temperature compensation amplifier is adjusted to show full level reading. Hence, adjustments are carried out only for full level at two extreme temperatures and this method of temperature compensation is partial. This contributes to an error of +/- 3% of span.
5.6.1 **Principle of new temperature compensation Technique**

This method utilizes the internal resistance variation of the coil with temperature and uses variation of internal resistance as a correction factor to compensate temperature effect. In the case of any given level, the internal resistance of the secondary coil increases with temperature. By connecting an external resistance, $R_{\text{ext}}$, there is a current flow such that the voltage drop within the internal resistance of the probe compensating the increase in the voltage induced within the secondary (Paris et al., 1976). Schematic of the circuit is shown in Fig. 5.8.

![Fig. 5.8 Schematic of continuous Level probe](image)

In Fig. 5.8, $E$ denotes induced voltage in secondary, $R_i$ denotes internal resistance of secondary, $i$ is the circulating current and $R_{\text{ext}}$ is the external resistance to be added for temperature compensation. Equation of the circuit in respect of a fixed level of sodium is as follows

$$E' = R_{\text{ext}}i = \frac{R_{\text{ext}}E}{R_{\text{ext}} + R_i}$$  \hspace{1cm} (5.6)

When the temperature varies, the voltage at the terminals of the $R_{\text{ext}}$ varies by $dE'$, Which is given by:
\[
\hat{E}' = \frac{R_{\text{ext}} x \partial E}{R_{\text{ext}} + R_i} - \frac{E_x R_{\text{ext}}}{(R_{\text{ext}} + R_i)^2} \partial R_i \tag{5.7}
\]

This variation should be reduced to zero (i.e.) \( \hat{E}' = 0 \);

Applying this condition to eqn (5.7) we get,

\[
R_{\text{ext}} = \frac{E_x \partial R_i}{\partial E} - R_i \tag{5.8}
\]

Eqn (5.8) can be written as,

\[
R_{\text{ext}} = \frac{E_x \Delta R_i}{\Delta E} - R_i
\]

Where,

- \( R_i \) = Internal resistance calculated by dividing primary voltage by primary current
- \( E \) = Secondary output
- \( R_{\text{ext}} \) = External resistance
- \( \Delta R_i \) = Difference in internal resistance at extreme temperature
- \( \Delta E \) = Difference in secondary voltage at extreme temperature.

For this calculation, primary resistance is considered as internal resistance of the secondary coil since the winding is bifilar. It is known that secondary output voltage is a function of sodium level, temperature and also the frequency of excitation. Equation 5.3 gives the value of external resistance, which takes care of temperature compensation. Effect of frequency on secondary output is obtained by plotting the value of external resistance and frequency for zero sodium level and full sodium level. The intersection point of these two curves gives value of external resistance for optimum frequency.

5.6.2. Experimental Validation

The prototype MI level probe is tested in sodium for implementing new method of temperature compensation technique. At different frequencies the data was collected in sodium for extreme temperature at zero and full level of sodium. The thermocouple measures
temperature of sodium in the heater vessel and required temperature is maintained by PID controller. The calibration procedure is, to fill the sodium at low temperature (200°C) so that the probe to be calibrated is fully immersed in sodium and measure the secondary millivolt and secondary winding resistance at different frequencies. Then quickly drain the sodium so as to maintain same temperature around the pocket at zero level. Measure the secondary millivolt and secondary winding resistance at different frequencies. Follow the same procedure for 550°C. Using Eqn.(5.3), calculate the external resistance at different frequencies. Then plot a graph between frequency versus external resistance. The optimum frequency of operation and the value of external resistance to be added for prototype level probe at extreme temperature (200 to 550°C) were obtained from intersection point of zero level and full level values as shown in Fig.5.9. This temperature compensation resistor was connected across the secondary of the probe. The level is measured and cross-checked with the Dip-Stick type level probe as reference probe.
### Table-5.1 Secondary output for different temperature with compensation using external resistor

<table>
<thead>
<tr>
<th>Sodium level (mm)</th>
<th>Secondary output (mV)</th>
<th>ΔE_T</th>
<th>Error in level (mm)</th>
<th>% Sec. voltage variation w.r.t Δe_ave for temp. from 200 °C-550 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>220°C</td>
<td>350°C</td>
<td>450°C</td>
<td>550°C</td>
</tr>
<tr>
<td>0</td>
<td>146.89</td>
<td>147.05</td>
<td>146.8</td>
<td>146.66</td>
</tr>
<tr>
<td>6000</td>
<td>117.56</td>
<td>117.6</td>
<td>117.35</td>
<td>117.3</td>
</tr>
<tr>
<td>ΔE</td>
<td>29.33</td>
<td>29.45</td>
<td>29.45</td>
<td>29.36</td>
</tr>
<tr>
<td>%S</td>
<td>19.97</td>
<td>20.03</td>
<td>20.06</td>
<td>20.02</td>
</tr>
<tr>
<td>Drop across primary (V)</td>
<td>4.759</td>
<td>6.299</td>
<td>7.317</td>
<td>8.453</td>
</tr>
<tr>
<td>Drop across primary (V)</td>
<td>4.748</td>
<td>6.143</td>
<td>7.12</td>
<td>8.134</td>
</tr>
</tbody>
</table>

ΔE: Change in secondary O/P from zero level to full level in mV at a particular temperature.

ΔE_T: Change in secondary O/P in mV w.r.t temperature.

Sensitivity = \[
\frac{\text{Change in secondary O/P from zero level to full level in mV}}{\text{Active length of the probe}}
\]

% S: % Variation of secondary O/P w.r.t level change at a given temperature

\[
\% S = \frac{\text{Change in secondary O/P (ΔE)}}{\text{Secondary O/P at zero level}} \times 100
\]

Error in level = \[
\frac{\text{Change in secondary O/P w.r.t temperature (mV)}}{\text{Sensitivity (mV/mm)}}
\]

% Sec. voltage variation w.r.t Δe_ave for temperature from 200°C – 550°C = \[
\frac{\Delta E_T}{\Delta E_{ave}}
\]
Fig. 5.10 Secondary output without temperature compensation

Fig. 5.11 Secondary output with temperature compensation using external resistor
Figure 5.10 shows the secondary millivolt versus level without temperature compensation. The procedure used is for various sodium temperatures and at different levels the secondary millivolt is measured by quickly draining the sodium so as to maintain constant temperature along the level probe. This experiment is carried out to assess the linearity of the probe at various levels at a uniform temperature. After connecting the resistance across the secondary, the graph between actual level and secondary millivolt with temperature compensation is plotted as shown in Fig. 5.11. The same quick draining procedure for maintaining the uniform temperature throughout the pocket is followed to obtain the graph.
To simulate the actual condition, for constant sodium temperature, at various sodium levels, the secondary millivolt is measured after stabilization of cover gas and sodium temperature. In this case, secondary millivolt is found to be independent of temperature. The schematic of the level measuring system with new temperature compensation is shown in Fig. 5.12. Another interesting fact observed is at different temperature ranges, the value of resistance as well as frequency of operation also changes. Table-5.2 below shows the different temperature ranges and the value of external resistance to be added.

**Table-5.2 Variation of frequency and resistance at different temperature ranges**

<table>
<thead>
<tr>
<th>Temperature range(°C)</th>
<th>Actual Value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freq. (kHz)</td>
<td>Resistance (Ω)</td>
</tr>
<tr>
<td>200-550</td>
<td>2.47</td>
<td>1535</td>
</tr>
<tr>
<td>250-550</td>
<td>2.54</td>
<td>1600</td>
</tr>
<tr>
<td>300-550</td>
<td>2.57</td>
<td>1640</td>
</tr>
<tr>
<td>350-550</td>
<td>2.57</td>
<td>1790</td>
</tr>
<tr>
<td>400-550</td>
<td>2.57</td>
<td>1980</td>
</tr>
<tr>
<td>450-550</td>
<td>2.47</td>
<td>2450</td>
</tr>
<tr>
<td>200-300</td>
<td>2.28</td>
<td>1290</td>
</tr>
<tr>
<td>200-400</td>
<td>2.42</td>
<td>1300</td>
</tr>
</tbody>
</table>

5.7 **IMPROVED ELECTRONICS CHASSIS**

The electronic chassis consists of two independent chains as shown in Fig. 5.13.

- an input chain
- an output chain.

The input chain feeds the primary winding of the probe with constant current and constant frequency. The output chain consists of receiver circuit. The isolated AC signal of secondary winding (5 mV to 250 mV) is processed by this circuit.

The exciter module has sinusoidal oscillator and a constant current drive circuit. The clock is derived from the crystal oscillator and using hardware based Direct Digital Synthesizer, the frequency of range 1 kHz to 10 kHz is selected with the resolution of 1 Hz.
As the signal level in the sensor is low of the order of few millivolts and the sensitivity is as low as 20%, a stringent requirement of sine wave of low distortion and amplitude stability is required in the electronics. The constant current source provides 0 to 200 mA rms isolated current, able to drive 150 Ohms with current stability better than ± 0.05 %. Isolation amplifier couple the sensor to both the energizing oscillator and the measuring unit to avoid earth loops and interfering pick up signals. As the resistor is connected across the secondary of the probe for providing temperature compensation, isolation amplifier with high input impedance is used to avoid the loading effect. The receiver module is having an active band pass filter in the range of 1 kHz to 5 kHz. In-situ test buttons shall be provided to increase / decrease the probe current at front to check the healthiness of the probe as well as the electronics. The receiver module has isolated input AC signal amplifier and isolated DC output. The following are the parameters of receiver:

- **Input signal range**: AC signal, 5 mV to 250 mV rms.
- **Input impedance**: $\geq 10^5$ ohms in the frequency band of 1 kHz to 5 kHz
- **Band width**: Lower 3 db point – less than 1 kHz
  Upper 3 db point – greater than 5 kHz
- **Stability**: 50 ppm/°C for ambient variation of 10 to 50°C
- **Linearity**: better than ±0.2% of full scale
- **Output**: 0 – 10V DC, 10 mA, isolated.

Trim pots for Zero & Span indication is provided at the front. High and low set points are provided as trip contacts. The level reading is indicated in 1 mm resolution with 0.01% of reading.
5.8 STUDIES TO IMPROVE THE SENSITIVITY OF THE PROBE

The sensitivity of the level probe can be increased by increasing the number of turns of the windings per unit length or increasing the coil winding diameter. Two bobbins of varying diameters of 30 mm and 32 mm were fabricated and tested in sodium for obtaining the sensitivity using new temperature compensation technique. All the three bobbin diameters 28 mm, 30 mm and 32 mm are tested in sodium in the same pocket of dimension 42.6 mm OD/36 mm ID. As there is 10% variation in pocket dimensions are expected, to eliminate this effect, levels probes are tested in the same pocket one after the other. The secondary mill volt was measured at two extreme operating temperatures from 200 to 550°C. Using the proposed temperature compensation technique, the sensitivity of 3 different probes are found out. From the experimental result it is found that for 32 mm bobbin diameter probe, the sensitivity is 26.5 % which is much better than the 28 mm bobbin diameter probe. Table-5.4 shows the experimental results. Further, 32 mm diameter bobbin probe is easily insertable up to 10 m pocket.
Table-5.3 Sensitivity studies for varying bobbin dimension

<table>
<thead>
<tr>
<th>Particulars</th>
<th>28 mm bobbin size level probe</th>
<th>30 mm bobbin size level probe</th>
<th>32 mm bobbin size level probe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency in kHz</td>
<td>2.25</td>
<td>2.35</td>
<td>2.55</td>
</tr>
<tr>
<td>External resistance $R_{ex}$ in $\Omega$</td>
<td>214.6</td>
<td>161</td>
<td>154.46</td>
</tr>
<tr>
<td>Sensitivity in %</td>
<td>19.66</td>
<td>23.137</td>
<td>26.50</td>
</tr>
<tr>
<td>Radial gap</td>
<td>4.31</td>
<td>3.31</td>
<td>2.31</td>
</tr>
<tr>
<td>% Accuracy</td>
<td>0.4</td>
<td>0.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>

5.9 DISCUSSION ON RESULTS

The proposed temperature compensation technique has been validated experimentally for prototype MI type continuous level probe. The method of calculating external resistance with minimum sodium data is established. Using this method, the temperature effect on level is reduced from 10.59% to 1.5% over an extreme temperature without change in sensitivity of the probe. The sensitivity of the probe is around 20% which is sufficient enough to adjust in the electronics. The linearity of the probe is determined to be 0.7%. This technique not only improves the accuracy to 1.5%, but also simplifies the electronic circuitry by eliminating the temperature compensation circuitry. Another interesting fact to be observed is at different temperature ranges, the value of resistance as well as frequency of operation also changes. A comparison of performances of a partial compensation probe against the resistor compensated probe is presented in Table 5.5. It is found that when the new method of temperature compensation is applied to short length probe, the optimum frequency increased to 4.6 kHz with an accuracy of 0.6 %. Studies have been made to improve the sensitivity of long length probe by changing the bobbin diameter. The sensitivity improves from 26.5% to 20%.
### Table-5.4 Results of partial compensation and resistor compensation probe

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Partial compensation probe</th>
<th>External resistor compensation probe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bobbin size</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Pocket</td>
<td>OD-34 mm/ ID-30mm</td>
<td>OD-42.6mm/ ID-36mm</td>
</tr>
<tr>
<td>Wall thickness of pocket</td>
<td>2 mm</td>
<td>2.7 mm</td>
</tr>
<tr>
<td>Radial gap between bobbin and pocket</td>
<td>1 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td>Accuracy</td>
<td>3 %</td>
<td>1.5 %</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>30 %</td>
<td>20 %</td>
</tr>
<tr>
<td>Active Length</td>
<td>2500 mm</td>
<td>9000 mm</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>2.73 kHz</td>
<td>2.5 kHz</td>
</tr>
</tbody>
</table>

### 5.10 MI TYPE DISCRETE LEVEL PROBE

The MI type level sensor has certain advantages over the resistance-type level detector. The MI type sensor works on non-contact principle whereas the resistance type sensor works based on its contact with sodium. Besides, MI type is kept in a well or pocket, and so maintenance of the sensor becomes easy. Also, the level sensor is not required to be mounted in the vessel at the time of integrity test of the vessel after fabrication at the manufacturer’s shop. Further, non-wetting of sodium with sensor does not affect the operation of MI type sensor. Considering the above advantages of MI type sensor, a prototype discrete level sensor was fabricated with 5 discrete levels (1000 mm active length and 1000mm non active length) and then tested in sodium. The bobbin diameter chosen for this application is 32 mm and located inside a pocket made of a standard pipe of (42.16 mm OD, 36.62 mm ID). The probe is tested in sodium and studies conducted on frequency response of probe.
5.11 CONSTRUCTION OF MI TYPE DISCRETE LEVEL PROBE

The sensing part of the probe consists of one primary winding and two layers of secondary windings as shown in Fig. 5.14. Bobbin is made of stainless steel former. The primary and secondary coils are wound at different positions where sensing is required. The primary winding of the bobbins are connected in series and secondary windings are individual as shown in Fig. 5.15. The primary and secondary windings are wound with 1 mm diameter mineral insulated cable with copper conductor. The probe is inserted in a stainless steel pocket. The primary is excited with a constant AC current at a fixed frequency. When the sodium surrounds the bobbin, induced signal in that bobbin secondary is minimal. When there is no sodium around the bobbin the induced signal in secondary is the maximum. The change in the induced signal of the secondary is utilized for sodium level detection. Since the coil lengths are much smaller (~ 20mm) compared to those used in the continuous type, the effect of sodium temperature coefficient on the level detection is negligible. For the same reason, the electronics is also made simpler.

![Fig. 5.14 Bobbin and windings of MI discrete level probe](image)
5.12 FREQUENCY RESPONSE STUDIES

Experiment has been conducted by exciting the primary coil with an AC constant current of 100 mA. Initially frequency response studies are carried out in sodium by varying the frequency of the primary current from 2 kHz to 5 kHz in steps of 0.5 kHz and the results are recorded. A graph is plotted between % Sensitivity vs Frequency. The plot is shown in Fig. 5.16. From the graph it is found that at a frequency of 2.5 kHz, the percentage variation of secondary output is almost constant for different temperature values.
5.13 DISCUSSION ON RESULT

From the experiments, it is found that due to temperature effect, the detection accuracy is around 6 mm from the centre of the bobbin. A value between minimum value of secondary output at bobbin immersed in sodium and maximum value of secondary output at bobbin in argon has been chosen as threshold value. Even though the threshold voltage is same for all the bobbins, each one triggers at different level due to sodium temperature variations as well as ±1 turn variation in coil windings.

5.14 CLOSURE

As commercially available level sensors cannot be used in hostile sodium environment, these sensors and instrumentation are specially designed based on mutual inductance type. The present invention is directed to a level measuring probe which is easy to use, has improved accuracy of measurement and provides an indication of level which is almost independent of the temperature of the liquid in which the probe is immersed. For large power reactors, long length level probe of active length 6 m and non active length of 3.6
m has been developed and tested in sodium to assess the sensitivity. A new temperature compensation technique employing external resistor has also been developed. This technique reduces the temperature effect on level from 10.59 % to 1.5 % over a wide temperature range of 200°C to 550°C without change in sensitivity of the probe. Using this method, the optimum frequency of excitation and the external resistance to be connected across the secondary coil have been determined simultaneously. The sensitivity of the long length level probe is estimated as 20 % around the operating frequency with an accuracy of 1.5 %. This technique not only improves the accuracy but also simplifies the electronic circuitry by eliminating the temperature compensation circuit. The linearity of the probe was found to be 0.7 % at different temperatures.

Studies have also been carried out to improve the sensitivity of the probe by varying the coil diameter in the range of 28-32 mm. The sensitivity of 32mm diameter bobbin has improved to 26.5 %. The radial gap is sufficient enough for easy insertion and withdrawal of the probe into the pocket of length 10 m.

A prototype MI type discrete level probe with 5 levels have been fabricated with 32 mm diameter bobbin and tested for its performance in sodium at different temperature. The operating frequency is determined to be 2.5 kHz where the temperature effect on secondary millivolt is minimum. The discontinuous level detection accuracy is ± 6 mm around the centre of the bobbin.

After successful development of prototype MI type continuous and discrete level probes, 29 nos of Continuous and discrete level probes of each have been fabricated for use in PFBR. The active length of the continuous level probe varies from 660 mm to 9300 mm. These level probes were characterized in sodium for obtaining optimum frequency of operation and external temperature compensation resistor.