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Studies on Conversion of Thermal Energy in to Electrical Energy using Ferromagnetic Nickel as Core Material

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Abstract. The voltage induced in the coil depends on number of turns of coil, rate of change of flux and permeability of core material. When these three factors are fixed the induced voltage becomes constant. It was observed that the induced voltage can be further increased, if the temperature of core material is increased. In addition to this, the variation of inductance and effective resistance of the coil with temperature is also measured. During the course of these investigations two parameters: Coefficient of induced voltage and Coefficient of permeability are measured [i]. These two parameters are measured for Nickel. These results are reported in this paper.

Keywords: Induced voltage, Inductance, Effective Resistance, Temperature, Coefficient of permeability and Coefficient of induced voltage.

1. Introduction

Earlier, the variation of initial permeability and maximum permeability with temperature was measured [ii] and maximum permeability was determined for ingot iron from the magnetization curves, recorded at different temperatures [iii]. But no formation is available on variation of induced voltage, variation of inductance and variation of effective resistance with secondary core temperature. In these studies all the above parameters are recorded and reported in this paper in detail.

2. EXPERIMENTAL METHOD

The experimental arrangement is shown in figure 1. is named as Horizontal set up. **A** is a ceramic tube of length 21 cm and diameter 10 cm. It is wound uniformly along its length with insulated copper wire of gauge number 16. **CD** is a mild steel cylindrical rod of length 23 cm and diameter 6 cm is placed inside the ceramic tube **A** as core. This arrangement acts as primary coil.

B is another ceramic tube of length 21 cm and diameter 10 cm. This is also wound uniformly along its length with insulated copper wire of gauge number 26. **EF** is a Nickel cylindrical rod of length 23 cm and diameter 5 cm is inserted in the ceramic tube **B** as core. This arrangement acts as secondary coil. The primary and secondary coils along with core materials are kept one after the other at a distance of 1 cm. A small hole is drilled at the end **F** of nickel rod (core) placed in secondary coil and chromel alumel thermo couple is inserted in to the hole. The thermo couple is connected to digital thermometer **(D_T)** to measure the temperature. The Nickel rod is heated in a Muffle furnace and transferred in to secondary coil **B** as core.

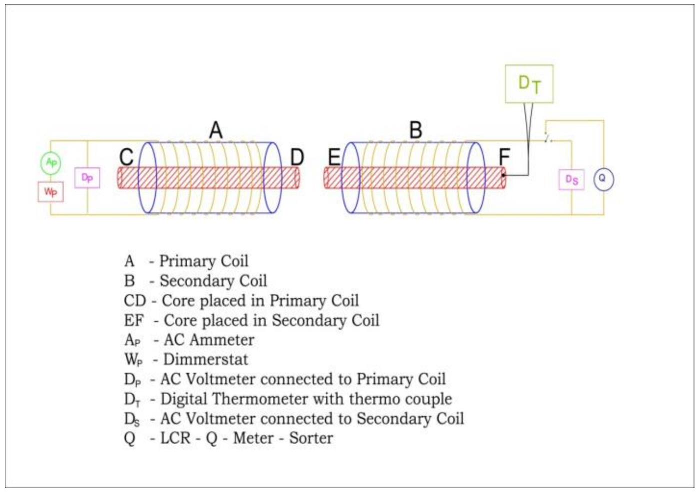

Figure 1: Experimental Arrangement (Horizontal set up)

The Dimmerstat **(W_P)** provides AC voltage at the supply frequency to the primary coil **A**. The secondary coil **B** is connected to AC voltmeter **(D_S)** and LCR- Q - Meter – Sorter **(Q)**.

The nickel rod **EF** is heated to 600 ^{0}C and kept at that temperature for one hour. Then the nickel rod **EF** is transferred to the secondary coil **B** as core. As the temperature of the nickel rod **EF** (core in the secondary coil) is decreasing induced voltage (V_S), effective resistance (R_S) and inductance (L_S) of the secondary coil are recorded from 500 ^{0}C (known as treatment temperature) until the rod cools to room temperature. The temperature intervals are chosen as 20 ^{0}C.

The same procedure is repeated by heating the nickel rod **EF** to 500 ^{0}C, 400 ^{0}C and readings are taken from 400 ^{0}C, 300 ^{0}C (known as treatment temperatures) until the rod cools to room temperature by maintaining the temperature intervals as 20 ^{0}C.

During the experiment the voltage (V_P) in the primary coil is maintained as constant i.e. 4.25 V.

3. RESULTS AND DISCUSSION

Graph 1 shows the variation of induced voltage (V_S) in the secondary coil with temperature for the secondary core heated up to 500 ^{0}C.

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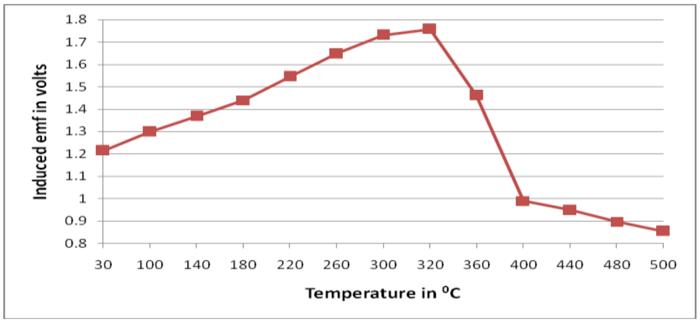


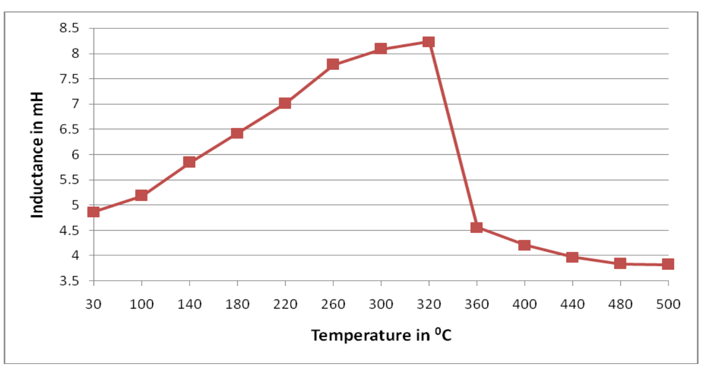
Graph 1: Variation of induced voltage of secondary coil with secondary core temperature at 500 ^{0}C.

From graph 1, the % increase in induced voltage (V_S) of secondary coil over a temperature range of 30 ^{0}C to 500 ^{0}C is calculated. From the graph it is clear that the induced voltage of the Secondary coil increases with increase of secondary core temperature up to 320 ^{0}C (Curie temperature of Nickel is 358 ^{0}C) and then decreases. From the variation of induced voltage (V_S) in the secondary coil with secondary core temperature, the coefficient of induced voltage (V_α) is measured using the formula given below.

Let V_1 and V_2 be the induced voltages at temperatures t_1 (30 ^{0}C) and t_2 (320 ^{0}C) respectively. The coefficient of induced voltage (V_α) is

$$V_\alpha = \frac{V_2 - V_1}{V_1 t_2 - V_2 t_1}$$

Graph 2 shows the variation of inductance (L_S) in the secondary coil with secondary core temperature for the same treatment. From graph 2, the % increase in inductance of secondary coil over a temperature range of 30 ^{0}C to 500 ^{0}C is calculated. From the graph it is clear that the inductance (L_S) of the secondary coil increases with increase of secondary core temperature up to 320 ^{0}C (Curie temperature of Nickel is 358 ^{0}C) and then decreases.



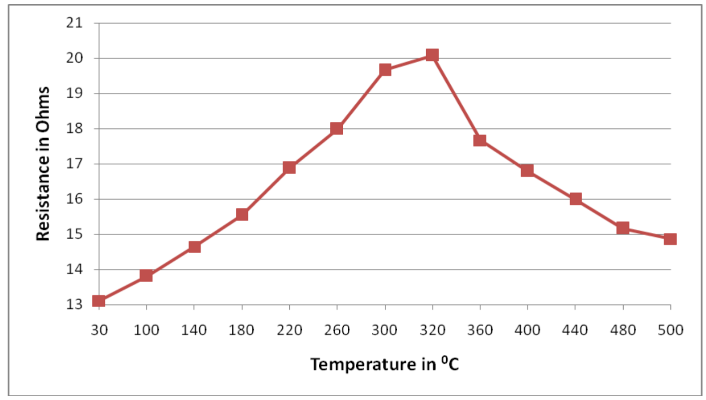
Graph 2: Variation of inductance of secondary coil with secondary core temperature at 500 ^{0}C.

From the variation of inductance (L_S) in the secondary coil with secondary core temperature, the coefficient of permeability (μ_α) is measured using the formula given below.

Let L_1 and L_2 be the inductances at temperatures t_1 (30 ^{0}C) and t_2 (320 ^{0}C). The inductance L is proportional to the permeability μ of the core. Therefore the coefficient of permeability (μ_α) is

$$\mu_\alpha = \frac{\mu_2 - \mu_1}{\mu_1 t_2 - \mu_2 t_1} = \frac{L_2 - L_1}{L_1 t_2 - L_2 t_1}$$

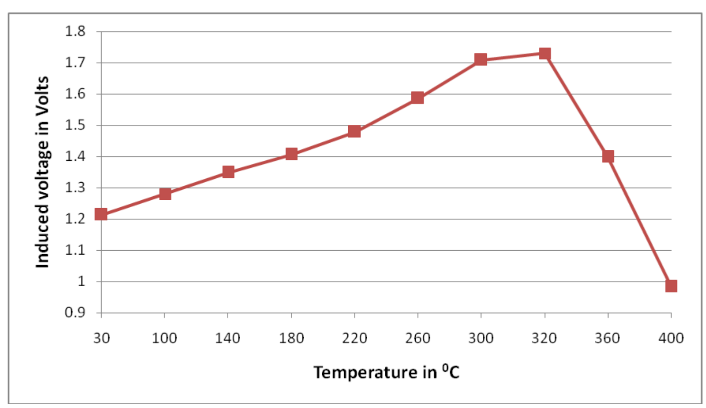
Graph 3 shows the variation of effective resistance (R_S) in the secondary coil with same temperature treatment.



Graph 3: Variation of effective resistance in the secondary coil with secondary core temperature at 500 ^{0}C.

The effective resistance (R_S) of the secondary coil increases up to 320 ^{0}C (Curie temperature of Nickel is 358 ^{0}C) and then decreases. This variation of effective resistance is not due to variation of DC resistance with temperature as generally observed. Thus the effective resistance of the secondary coil behaves in a peculiar way. The effective resistance measured in this experiment is not the DC resistance of the secondary coil. It is the resistance of the secondary coil due to hysteresis and eddy current losses in the core material. During the course of these studies the temperature of the secondary coil increased to a maximum of 100 ^{0}C. Similar behavior is observed in another experimental set-up [v].

Similar kind of behavior is observed for the nickel rod (Core in the secondary coil) heated and readings are taken from 400 ^{0}C. The corresponding graphs are also shown below.



Graph 4: Variation of induced voltage of secondary coil with secondary core temperature at 400 ^{0}C.

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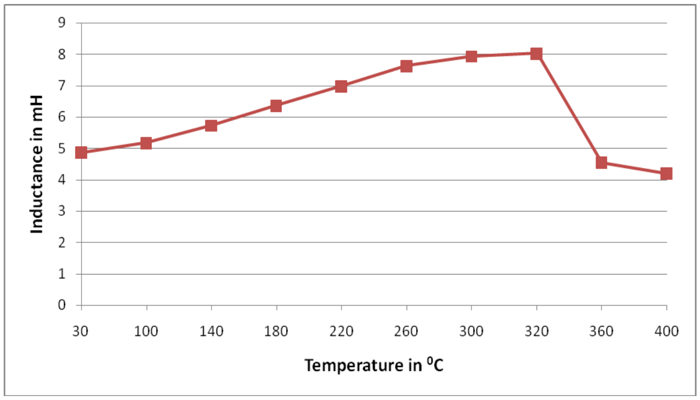
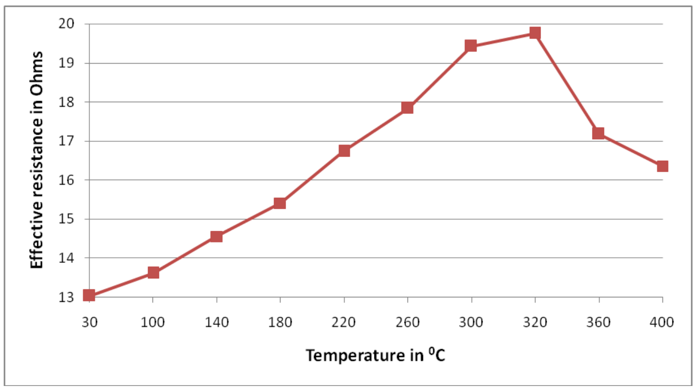
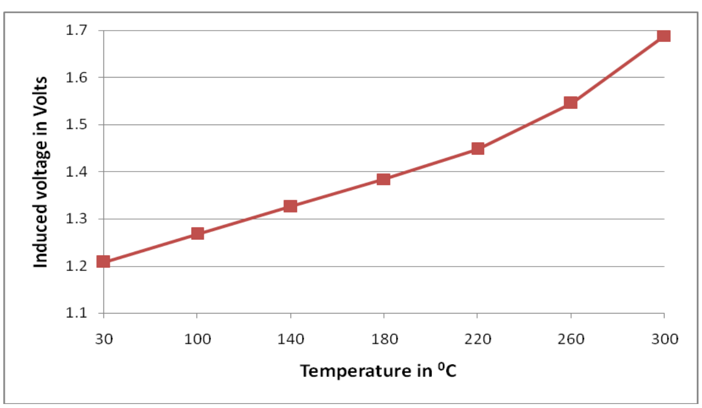


Graph 5: Variation of inductance of secondary coil with secondary core temperature at 400 ^{0}C.

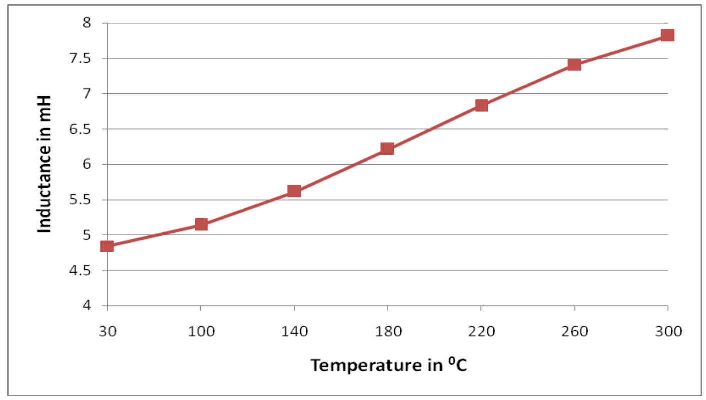


Graph 6: Variation of effective resistance in the secondary coil with secondary core temperature at 400 ^{0}C.

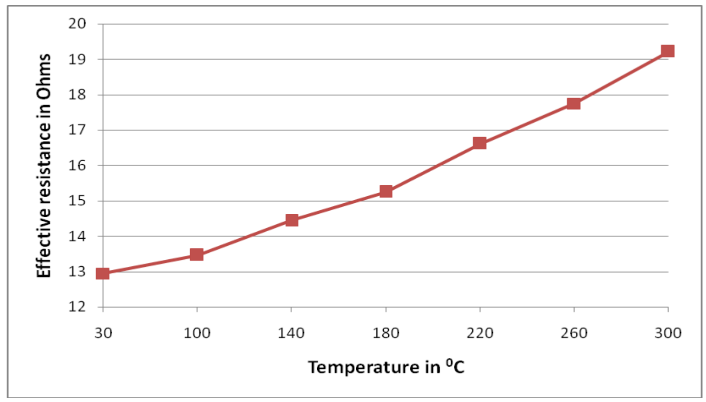
The Nickel rod is heated and readings are taken from 300 ^{0}C (below the Curie temperature of Nickel at 358 ^{0}C). In this study, the induced voltage (V_S), inductance (L_S) and effective resistance (R_S) of the secondary coil increases with increase of secondary core temperature. The corresponding graphs are also shown below.



Graph 7: Variation of induced voltage of secondary coil with secondary core temperature at 300 ^{0}C.



Graph 8: Variation of inductance of secondary coil with secondary core temperature at 300 ^{0}C.



Graph 9: Variation of effective resistance in the secondary coil with secondary core temperature at 300 ^{0}C.

The increase in inductance in secondary coil is due to increase in permeability with secondary core temperature [ii].

These experiments show the induced voltage in the secondary coil (by placing ferromagnetic material as secondary core - in this study Nickel rod) depends on temperature of secondary core material. And the increase in induced voltage (V_S) in secondary coil is more than given by Faradays law i.e. $\mathbf{e = n}\frac{d\phi}{dt}$

Here e is induced voltage (emf), n is number of turns in the coil, $\frac{d\phi}{dt}$ is rate of change of flux

The Faradays law can be modified as $\mathbf{e = n}\frac{d\phi}{dt}\,\mathbf{t^x}$ by adding temperature dependent term t. Here t is treatment temperature and x is slope taken from the Ln - Ln graph drawn between induced voltage (V_S) and secondary core temperature.

4. Conclusions

1. The % increase in induced voltage (V_S) in secondary coil is
44.69 at 500 ^{0}C.
42.62 at 400 ^{0}C.
39.73 at 300 ^{0}C.

2. The coefficient of induced voltage (V_α) in Nickel is
1.6157 X 10^{-3} $^0C^{-1}$ at 500 ^{0}C.
1.5375 X 10^{-3} $^0C^{-1}$ at 400 ^{0}C.

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1.5396 X $10^{-3}\,{}^{0}C^{-1}$ at 300 ^{0}C.

3. The % increase in inductance (L_S) in secondary coil is
69 at 500 ^{0}C.
65.08 at 400 ^{0}C.
61.49 at 300 ^{0}C.

4. The coefficient of permeability (μ_α) in Nickel is
2.5633 X $10^{-3}\,{}^{0}C^{-1}$ at 500 ^{0}C.
2.4065 X $10^{-3}\,{}^{0}C^{-1}$ at 400 ^{0}C.
2.4449 X $10^{-3}\,{}^{0}C^{-1}$ at 300 ^{0}C.

5. The % increase in effective resistance (R_S) in secondary coil is 53.16 at 500 ^{0}C.
51.53 at 400 ^{0}C.
48.41 at 300 ^{0}C.

6. The optimum temperature identified in this experimental set up (Horizontal set up) using Nickel as core material in the secondary coil is 320 ^{0}C.

In these studies, the effective resistance begins to decrease as the secondary core temperature approaches Curie temperature of nickel (358 ^{0}C). It suggests that the hysteresis and eddy current losses begin to decrease at/near the Curie temperature.

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