Studies on Thermal Treatment of Ferromagnetic Cobalt as Core Material in Secondary Coil

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Abstract:

In coil systems, the induced electromotive force (emf) is influenced by several factors: the number of turns in the coil, the rate of change of magnetic flux, and the permeability of the core material. When these factors are constant, the induced emf remains stable. However, experiments with a Nickel-cored coil have shown that increasing the temperature of the core material can further enhance the induced emf, given a consistent rate of change of flux. This led to the introduction of two parameters: the coefficient of permeability and the coefficient of induced emf [1]. In the present paper, these two parameters were measured for Cobalt and also the variation of emf and inductance are examined and reported in detail by taking ferromagnetic Cobalt material as core of a secondary solenoid when subjected to thermal treatment.

Keywords: Induced voltage, Inductance, Temperature, Coefficient of Permeability and induced voltage and Ferromagnetic Cobalt.

1. INTRODUCTION:

Earlier, the variation of initial and maximum permeability of ferromagnetic materials with temperature were measured [2] and maximum permeability were of the ingot iron was determined from the magnetization curves, recorded at different temperatures [3]. But there is no information about the changes in induced voltage, inductance with temperature. The emf induced in the coil depends on the number of turns of coil, rate of change of flux and permeability of core material. When these three factors are fixed the induced emf becomes constant. It was observed that emf can be further increased if the temperature of ferromagnetic core material is increased. The inductance (L_0) of an air core solenoid of length l is $L_0 = \mu_0 N_2 S/l$, where N is number of turns and S is area of cross section. The inductance L of the same solenoid with a ferro magnetic core of relative permeability μ_r is $L = \mu_0\mu_r N_2 S/ l$. The ratio L to L_0 gives the relative permeability μ_r of the core material.

2. EXPERIMENTAL METHOD:

The experimental arrangement depicted in Figure 1 is referred to as the Horizontal setup. Component A is a ceramic tube with a length of 21 cm and a diameter of 10 cm. It is uniformly wound with insulated copper wire of gauge number 16 along its length. Inside the ceramic tube, there is a mild steel cylindrical rod, labeled CD, with a length of 23 cm and a diameter of 6 cm, serving as the core. This assembly functions as the primary coil. The experimental setup also includes component B, another ceramic tube with a length of 21 cm and a diameter of 10 cm. This tube is wound uniformly with insulated copper wire of gauge number 26. Inside this ceramic tube is a cobalt cylindrical rod, labeled EF, with a length of 23 cm and a diameter of 5 cm, serving as the core. This arrangement forms the secondary coil.

The primary and secondary coils, along with their respective core materials, are placed next to each other with a 1 cm gap between them. A small hole is drilled at the end F of the cobalt rod (core) in the secondary coil, into which a chromel-alumel thermocouple is inserted. This thermocouple is connected to a digital thermometer (DT) to measure the temperature. The cobalt rod is heated in a muffle furnace and then transferred into the secondary coil B as its core. A Dimmer stat (WP) provides AC voltage at the supply frequency to the primary coil A. The secondary coil B is connected to an AC voltmeter (DS) and an LCR-Q Meter-Sorter (Q) to measure the voltage and other parameters.

The Cobalt rod EF is heated to 1150 °C and maintained at that temperature for one hour. It is then transferred to the secondary coil B as the core. As the temperature of the Cobalt rod EF (acting as the core in the secondary coil) decreases, the induced voltage (V_S) and inductance (L_S) of the secondary coil are recorded from 1100 °C down to room temperature, in 20 °C intervals.

This procedure is repeated by heating the Cobalt rod EF to 1100 °C and 1000 °C, and readings are taken as the rod cools from 1000 °C and 900 °C respectively, to room temperature, maintaining the same 20 °C intervals. Throughout the experiment, the voltage (V_P) in the primary coil is kept constant at 4.25 V.

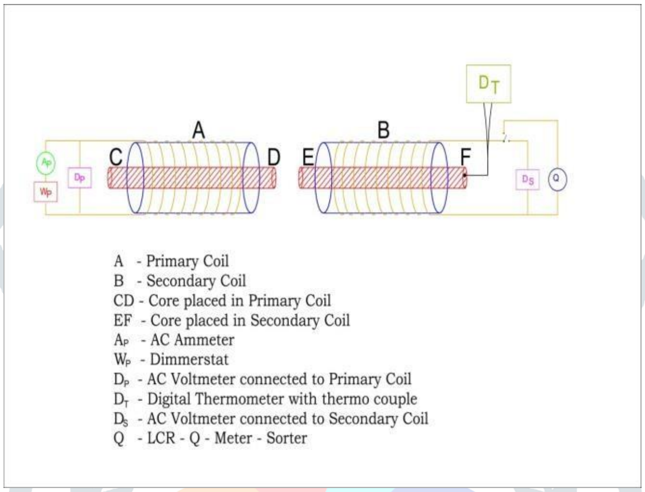


Figure 1: Experimental Arrangement(Horizontal set up)

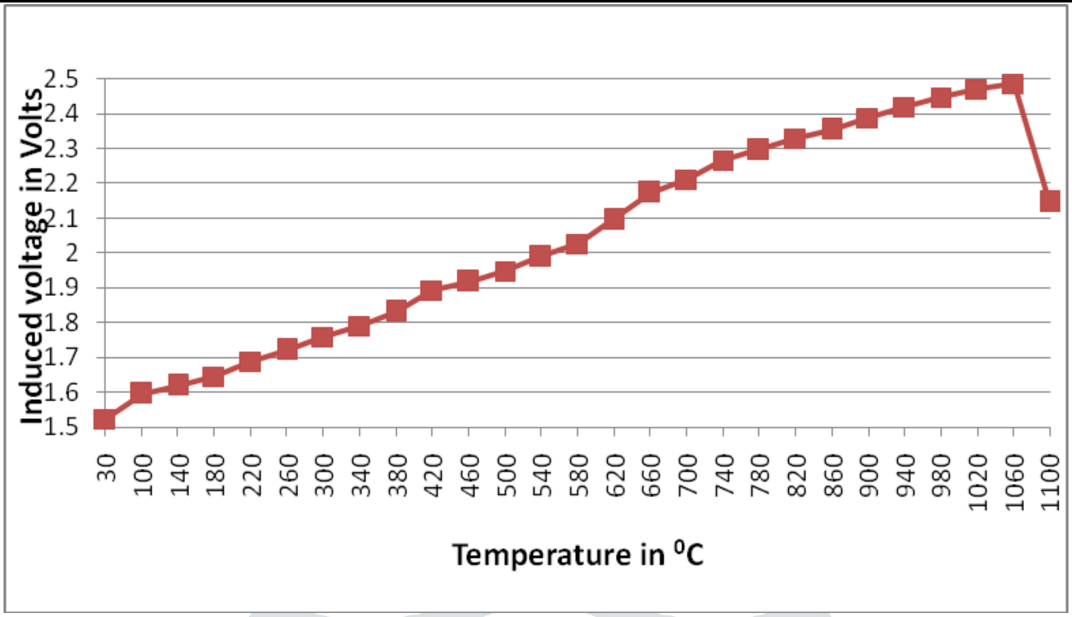
3. RESULTS AND DISCUSSION:

Graph 1 illustrates the variation of induced voltage (V_S) in the secondary coil as a function of temperature for the core heated up to 1100 °C. The temperature decreases in intervals of 20°C, starting from 1100 °C down to room temperature, showing how V_S changes with the cooling of the Cobalt rod EF.

From Graph 1, the percentage increase in induced voltage (V_S) of the secondary coil over a temperature range of 30°C to 1100 °C is calculated. The graph indicates that the induced voltage of the secondary coil increases with an increase in core temperature up to 1070 °C, which is close to the Curie temperature of Cobalt (1131 °C), and then decreases. Using the variation of induced voltage (V_S) in the secondary coil with core temperature, the coefficient of induced voltage (Vα) is determined using the formula:

Let V1 and V2 be the induced voltages at temperatures t1 (30 °C) and t2 (1070 ^{0}C) respectively. The coefficient of induced voltage (Vα) is

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

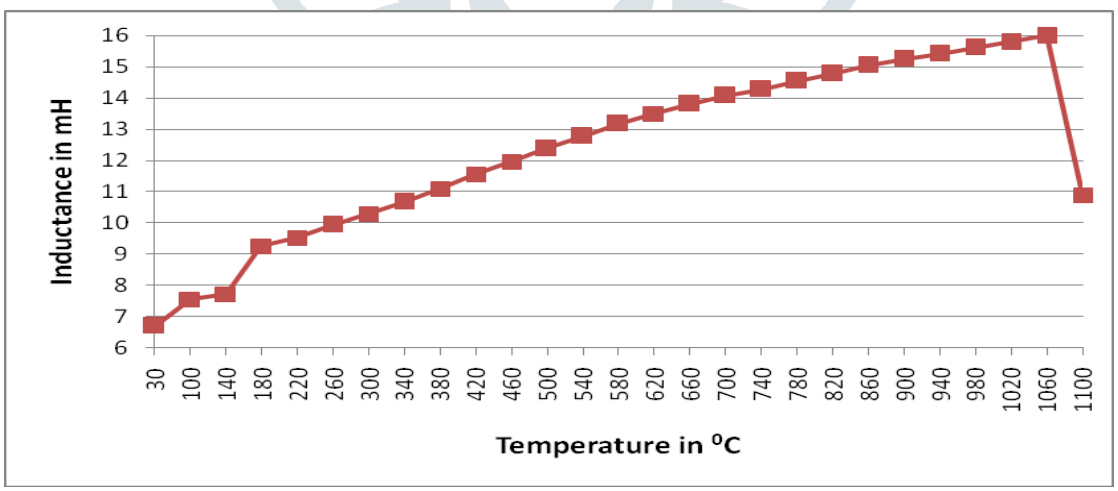


Graph 1: Variation of induced voltage of secondary coil with core temperature at 1100 ^{0}C

Graph 2 illustrates the variation of inductance (L_S) in the secondary coil as a function of temperature for the same treatment. The percentage increase in inductance of the secondary coil over a temperature range of 30 °C to 1100 °C is calculated. The graph indicates that the inductance (L_S) of the secondary coil increases with an increase in core temperature up to 1070 °C, which is close to the Curie temperature of Cobalt (1131 °C), and then decreases.

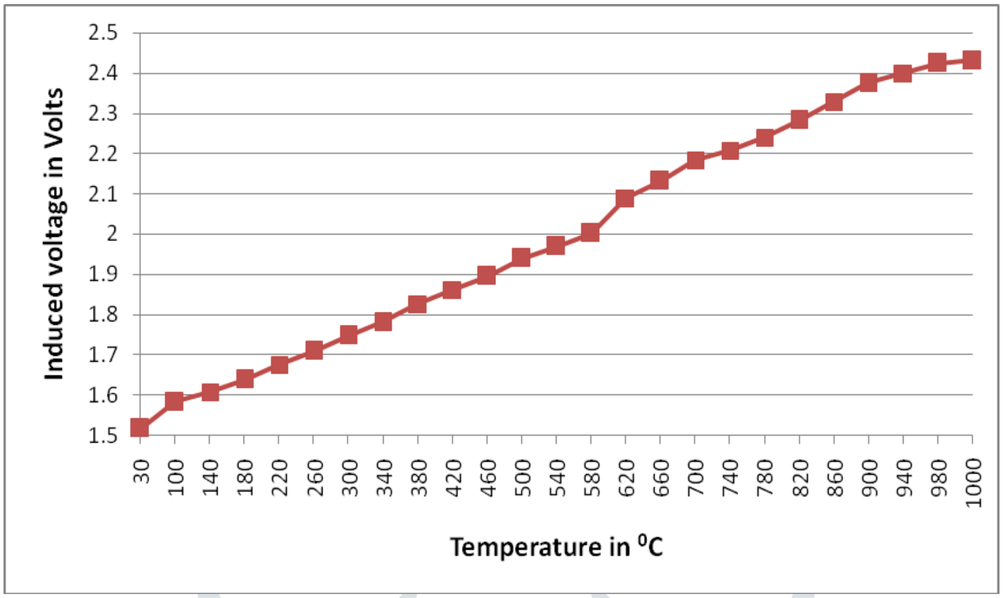
From the variation of inductance (L_S) in the secondary coil with core temperature, the coefficient of permeability (μα) is determined using the formula. Let L_1 and L_2 be the inductances at temperatures t1 (30 °C) and t2 (1070 °C), respectively. The inductance L is proportional to the permeability (μ_α) of the core.

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

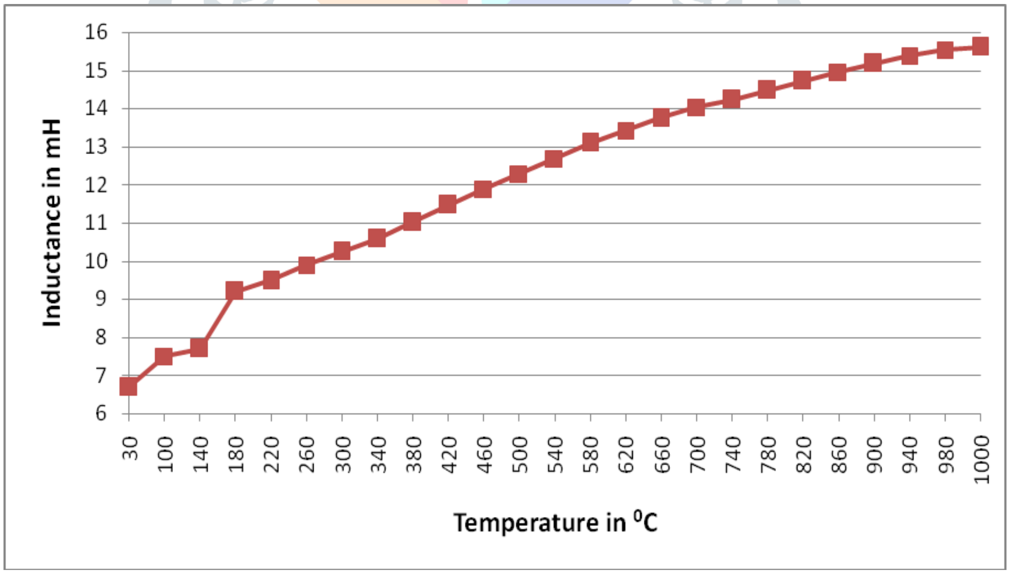


Graph 2: Variation of inductance of secondary coil withcore temperature 1100 ^{0}C

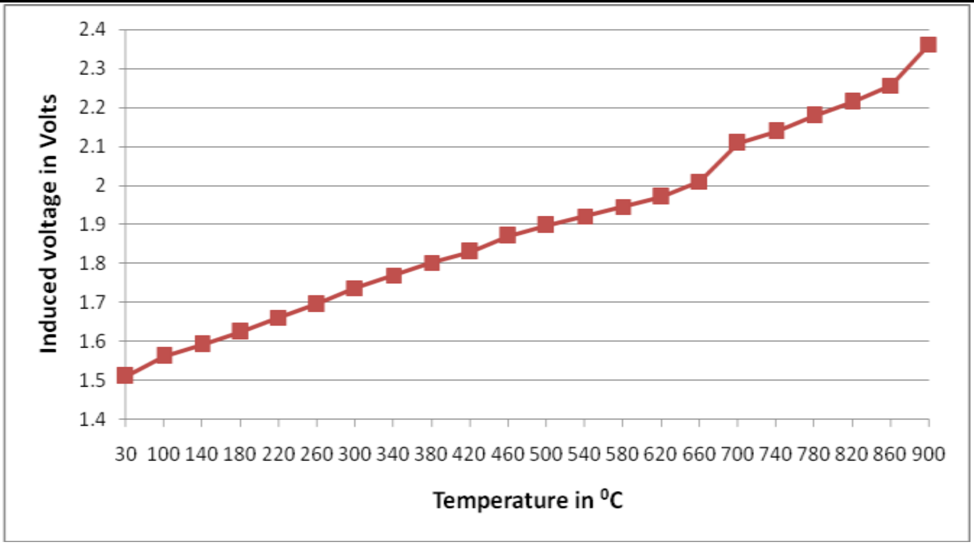
The Cobalt rod (core in the secondary coil) is heated to 1100 °C and 1000 °C, with readings taken as the rod cools from 1000 °C and 900 °C, respectively. The corresponding graphs show that at these treatment temperatures (1000 °C and 900 °C, both below the Curie temperature of Cobalt at 1131 °C), all parameters—induced voltage (V_S) and inductance (L_S) of the secondary coil—increase with an increase in temperature up to 1000 °C and 900 °C. The corresponding graphs for these parameters are shown in graphs 3, 4, 5 and 6.



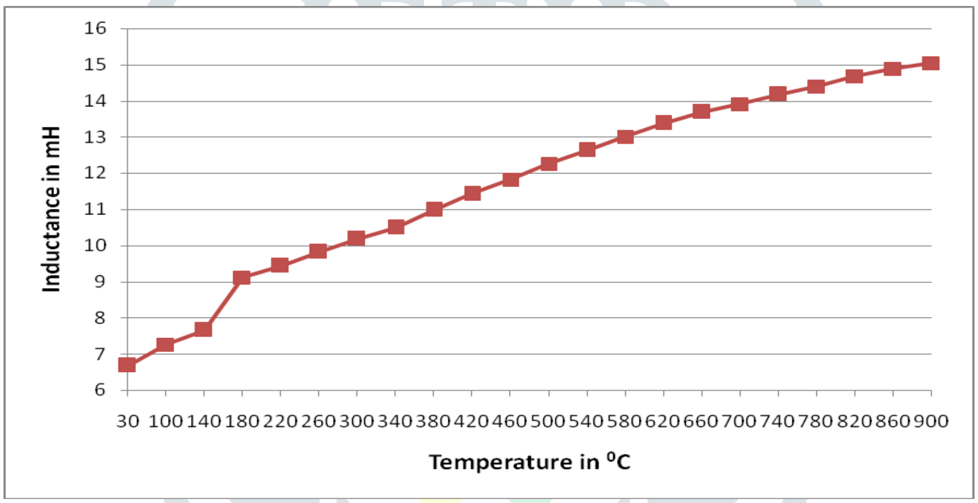
Graph 3: Variation of induced voltage of secondary coilwith core temperature 1000 ^{0}C



Graph 4: Variation of inductance of secondary coil withcore temperature 1000 ^{0}C



Graph 5: Variation of induced voltage of secondary coilwith core temperature 900 ^{0}C



Graph 6: Variation of inductance of secondary coil withcore temperature 900 ^{0}C

The increase in inductance in the secondary coil is due to the increase in permeability with core temperature (2). These experiments demonstrate that the induced voltage in the secondary coil (with a ferromagnetic material, specifically a Cobalt rod, as the core) depends on the temperature of the core material. Additionally, the increase in induced voltage (V_S) in the secondary coil is greater than what is predicted by Faraday's law.

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

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

The Faradays law can be modified as $e = n\, t^x \frac{d\emptyset}{dt}$ 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 (VS) and core temperature.

4. CONCLUSIONS:

1. The % increase in induced voltage (V_S) in secondary coil:

   63.38 at 1100 ^{0}C.

   60.25 at 1000 ^{0}C

   56.42 at 900 ^{0}C.

2. The coefficient of induced voltage (V_α) in Cobalt:

   6.2083 X 10^{-4} $^0C^{-1}$ at 1100 ^{0}C

   6.3293 X 10^{-4} $^0C^{-1}$ at 1000^0 C

   6.6141 X 10^{-4} $^0C^{-1}$ at 900 ^{0}C.

3. The % increase in inductance (L_S) in secondary coil:

   140.47 at 1100 ^{0}C.

   133.44 at 1000 ^{0}C.

   125.0 t 900 ^{0}C.

4. The coefficient of permeability (μ_α) in Cobalt:

   1.4077 X 10^{-3} $^0C^{-1}$ at 1100 ^{0}C.

   1.4349 X 10^{-3} $^0C^{-1}$ at 1000 ^{0}C.

   1.5015 X 10^{-3} $^0C^{-1}$ at 900 ^{0}C.

5. The transition temperature identified in this experiment using Cobalt as core material in the secondary coil is 1070 ^{0}C.

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