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Reduction of Iron Losses in a Transformer using Embeded Core

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Abstract

It is almost impossible to reduce the iron losses completely; however these can be reduced to a certain extent Here we have made an effort to reduce the eddy current loss by reducing the iron area of core It has been done by embedding an anti-ferromagnetic bar of copper in iron core by keeping total area constant As we know that eddy current loss occurs in ferromagnetic material instead of anti-ferromagnetic material so path length of eddy current will get reduced by inserting anti ferromagnetic bar in hollow part of ferromagnetic core As we know that eddy currents flow around the magnetic flux while enclosing it, the embedding of copper bar will reduce the path length of eddy current thus reducing the total eddy current loss.

Keywords: Transformer, separation of hysteresis and eddy current loss, embedded core, anti-ferromagnetic material.

1. Introduction

The transformer is one of the simplest of electrical devices Its basic design, materials, and principles have changed little over the last one hundred years, yet transformer designs and materials continue to be improved Transformers are essential in high voltage power transmission providing an economical means of transmitting power over large distances In electronic circuitry, new methods of circuit design have replaced some of the applications of transformers, but electronic technology has also developed new transformer designs and applications Transformers come in a range of sizes from a thumbnail-sized coupling transformer hidden inside a stage microphone to Giga watt units used to interconnect large portions of national power grids, all operating with the same basic principles

This paper contain basic principles, losses of transformer, separation of eddy current and hysteresis losses, how to minimize losses and records and calculations The basic aim of this paper is to minimize iron losses in transformer by using anti ferromagnetic material

2. Basic Principles

1 Analogy: The transformer may be considered as a simple two-wheel 'gearbox' for electrical voltage and current The primary winding is analogous to the input shaft and the secondary winding to the output shaft In this comparison, current is equivalent to shaft speed, voltage to shaft torque In a gearbox, mechanical power is constant and is equivalent to electrical power which is also constant

The gear ratio is equivalent to the transformer step-up or step-down ratio A step-up transformer acts analogously to a reduction gear (in which mechanical power is transferred from a small, rapidly rotating gear to a large, slowly rotating gear): it trades current (speed) for voltage (torque), by transferring power from a primary coil to a secondary coil having more turns A step- down transformer acts analogously to a multiplier gear (in which mechanical power is transferred from a large gear to a small gear): it trades voltage (torque) for current (speed), by transferring power from a primary coil to a secondary coil having fewer turns

2 Flux coupling laws: A simple transformer consists of two electrical conductors called the primary winding and the secondary winding If a time-varying voltage is applied to the primary winding of turns, a current will flow in it producing a magneto motive force (MMF) Just as an electromotive force (EMF) drives current around an electric circuit, so MMF drives magnetic flux through a magnetic circuit The primary MMF produces a varying magnetic flux in the core, and induces a back electromotive force In accordance with Faraday's Law, the voltage induced across the primary winding is proportional to the rate of change of flux:

$$V_P = N_p \, d\Phi_p / dt \qquad (1)$$

Similarly, the voltage induced across the secondary winding is:

$$V_s = N_s \, d\Phi_s / dt \qquad (2)$$

With perfect flux coupling, the flux in the secondary winding will be equal to that in the primary winding, thus:

$$V_P / V_s = N_p / N_s \qquad ,(3)$$

The EMF in the secondary winding, if connected to an electrical circuit, will cause current to flow in the secondary circuit The MMF produced by current in the secondary opposes the MMF of the primary and so tends to cancel the flux in the core Since the reduced flux reduces the EMF induced in the primary winding, increased current flows in the primary circuit The resulting increase in MMF due to the primary current offsets the effect of the opposing secondary MMF In this way, the electrical energy fed into the primary winding is delivered to the secondary winding Neglecting losses, for a given level of power transferred through a transformer, current in the secondary circuit is inversely proportional to the ratio of secondary voltage to primary voltage

In a practical transformer, the higher-voltage winding will have more turns, of smaller conductor cross-section, than the lower- voltage windings

3. Practical Considerations

Because the windings are identical for both transformers, the assumption is made that the increase in eddy current for the windings is equal in both cases

Total increase in coil losses due to harmonic currents is assumed equal two transformers of 250KVA were used for field testing One transformer was made with anti-ferromagnetic and Another with Normal core metal Both transformers were designed as per REC specifications

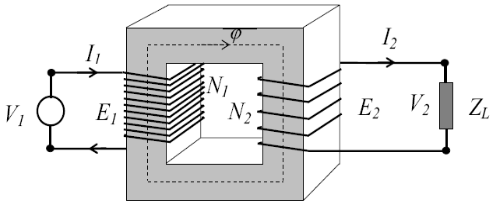


Fig 1: Single phase pole-mounted step- down transformer

4. Losses in a Transformer

An ideal transformer would have no losses, and would therefore be 100% efficient In practice energy is dissipated due both to the resistance of the windings (known as copper loss), and the magnetic effects primarily attributable to the core (known as iron loss) Transformers are in general highly efficient, and large power transformers (around 100 MVA and larger) may attain an efficiency as high as 9975% The losses arise from:

1. *Winding resistance:* Current flowing through the winding causes resistive heating

2. *Eddy currents:* Induced currents circulate in the core and cause its resistive heating
3. *Stray losses:* Not all the magnetic field produced by the primary is intercepted by the secondary A portion of the leakage flux may induce eddy currents within nearby conductive objects such as the transformer's support structure, and be converted to heat The familiar hum or buzzing noise heard near transformers is a result of stray fields causing components of the tank to vibrate, and is also from magnetostriction vibration of the core
4. *Hysteresis losses:* Each time the magnetic field is reversed, a small amount of energy is lost to hysteresis in the magnetic core
5. *Mechanical losses:* The alternating magnetic field causes fluctuating electromagnetic forces between the coils of wire, the core and any nearby metalwork, causing vibrations and noise which consume power
6. *Magnetostriction:* The flux in the core causes it to physically expand and contract slightly with the alternating magnetic field, an effect known as magnetostriction This in turn causes losses due to frictional heating in susceptible ferromagnetic cores
7. *Cooling system:* Large power transformers may be equipped with cooling fans, oil pumps or water-cooled heat exchangers designed to remove the heat caused by copper and iron losses The power used to operate the cooling system is typically considered part of the losses of the transformer

5. Seperation of Hysteresis and Eddy Current Losses

Eddy current losses can be reduced in a core by reducing the area of ferromagnetic material by embedding the equal area of anti-ferromagnetic material in the same core

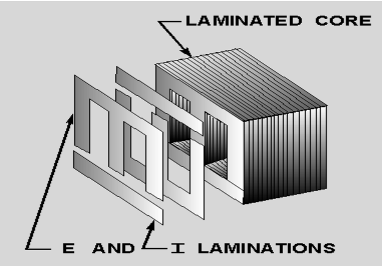


Fig 2

The losses which occur in transformer are:

1. *Copper losses Pc:* Here we will calculate copper loss for one embedded bar similarly losses can be calculated for all other bars

$$P_C=I^2R \tag{4}$$

2. *Iron or core losses Pi:* Iron loss occurs in the magnetic core of the transformer This loss is the sum of hysteresis loss (P_h) and Eddy current loss (P_e)

$$P_i=P_h+P_e \tag{5}$$

$$P_i=K_h\ fB_m{}^n + Kef^2B^2{}_m \tag{6}$$

Where K_h = Proportionality constant which depends upon the volume and quality of the core material and the units used, K_e= Proportionality constant whose value depends upon the volume and resistivity of the core material, thickness of laminations and units used, B_m=Maximum flux density in the core, f=Frequency of the alternating flux

The exponents n varies in the range 15 to 25 depending upon the ferromagnetic material for a given $B_{m,}$ the hysteresis loss varies directly as the frequency and the Eddy current loss varies as the square of the frequency That is,

$$P_h\ \alpha\ f \text{ or } P_h=af \tag{7}$$

$$P_e\ \alpha\ f^2 \text{or } P_e=bf^2 \tag{8}$$

$$P_i=af+bf^2 \tag{9}$$

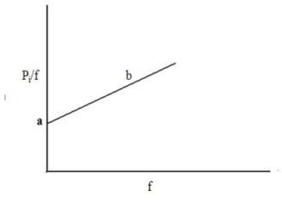
Where a and b are constants

For separation of these two losses the no load test is performed on the transformer However, the primary of the transformer is connected to a variable frequency and variable sinusoidal supply and the secondary is open circuited Now,

$$V=444f\acute{\O}_mT \text{ or } V/f=444B_mA_iT \tag{10}$$

$$Pi/f=a+bf \tag{11}$$

During this test, the applied voltage V and frequency f are varied together so that (V/f) is kept constant The core loss is obtained at different frequencies by (Pi/f) versus frequency f graph Thus, knowing the constants a and b, hysteresis and eddy current losses can be separated



Graph 1

6. Eddy Current Loss

When the probe is brought in close to a conductive material, the probes changing magnetic field generates current flow in the material

By measuring changes in the resistance and inductive reactance of the coil, information can be gathered about the test material

The eddy currents produce their own magnetic fields that interact with the primary magnetic field of the coil

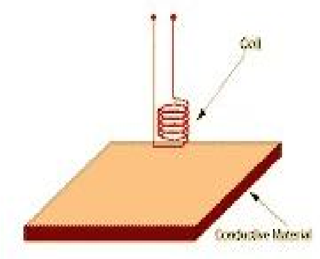


Fig 3(a)

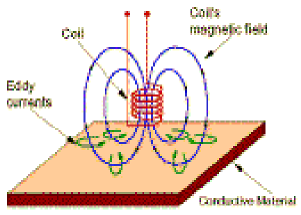


Fig 3(b)

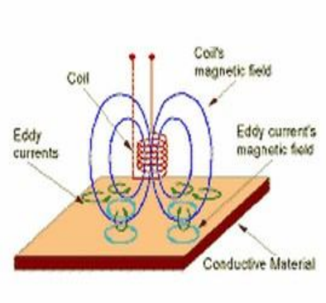


Fig 3(c)

7. How Eddy Current Loss is Minimized by using Laminated Core

Assume that a changing magnetic flux is passing through a certain square cross sectional area of the transformer core Look at a loop of current enclosing that flux The power dissipated in that particular loop is proportional to the square of the area enclosed by that loop (A) divided by the length of the path (L) If you divide that square into two rectangles by laminating the core, the area enclosed in the loop will be cut in half while the length will be reduced to 3/4 of the original length The result will be two loops of current with a total power dissipation of 2 $(5A)^2$/075L That makes the sum of the power dissipated in the two smaller loops two thirds of the power dissipated in the original loop More laminations reduce the dissipation even more

8. Total Loss Record

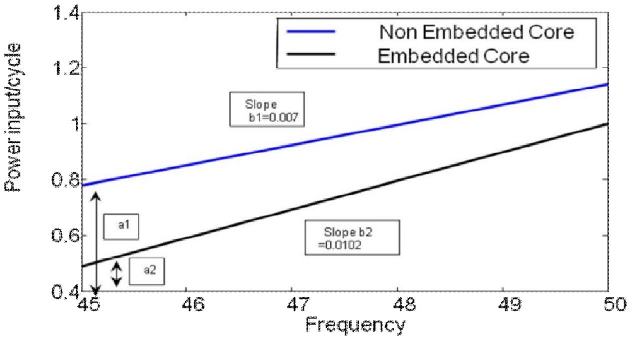
Table 1: Loss Record with Non Embedded core:

S No	Frequency (Hz)	Current (A)	Wattmeter Reading(W)	Generated Voltage(V)	Iron loss (Pi)	Pi/f Ratio
1	45	105	112	336	220 1	0489
2	46	105	117	345	278 9	0604
3	47	105	121	354	318 1	0676
4	48	105	128	363	388 1	0808
5	50	105	140	388	500 1	1000

Table 2: Loss Record with Embedded core:

S No	Frequency (Hz)	Current (A)	Wattmeter Reading(W)	Generated Voltage(V)	Iron loss (Pi)	Pi/f Ratio
1	45	107	125	340	350 1	0778
2	46	107	128	352	388 1	0843
3	47	107	133	358	418 1	0932
4	48	107	135	369	458 1	0954
5	50	107	147	386	570 1	1140

9. Calculation for Total Iron Loss



Graph 2

1 Calculation for eddy current losses:
For non-Embedded core:
R= resistance of winding = 809 Ω
Pc= copper loss= I^2R = 8999 W
Pi=Pt-Pc= 125-8999= 3501 W, where Pi= input power and Pt= total power
Pi/f = 0778 W/Hz
From above graph, b =000724
Pe= eddy current loss= bf^2 = $000724*50^2$= 181 W
For Embedded core:
R= resistance of winding = 809 Ω
Pc= copper loss= I^2R = 8999 W
Pi=Pt-Pc= 112-8999= 2201 W, where Pi= input power and Pt= total power Pi/f=0489 W/Hz
From above graph, b =00102
Pe= eddy current loss = bf^2 = $00102*50^2$= 255

2 Calculation for hysteresis losses:
Non-Embedded core:

From graph a=078
We know that, P_h = af= 078*50 =39 W
Embedded core:
From graph a = 047
We know that, P_h=af =047*50 =23 W
Therefore total iron losses in non-Embedded core are: P_h + Pe = (39+181) = 571 W

Total iron losses in Embedded core are: Ph + Pe = (255+23) = 485 W

Reduction in iron losses are:

(Loss in non-Embedded core – loss in Embedded core)/(loss in non-Embedded core)

(571-485)/571 * 100 = 1506 %

10. Results

S No	Losses	Non-Embeded Core	Embeded Core	Effect
1	Eddy Current Loss	181W	255W	29% Increase
2	Hysteresis Loss	39W	23W	41% Decrease
3	Total Iron Loss	571W	485W	1506% Decrease

Over all core loss is reducing in comparison to the non-Embedded core with embedded core

11. Economical Aspects

A 240 VA 1-Ǿ transformer is in circuit continuously For 8 hours a day the load is 160W at 08pf For 6 hours, the load is 80W at the unity pf and for the remaining period of 24 hours it runs on no-load Full load copper losses are 302W and the iron losses are 16W (a) Find total cost of the total power supplied for one year @380 Rs/W (b) find out the total cost when iron losses reduce to 1506%find out the total profit

(a) Full load output = 240VA, Full-load copper losses, Pc = 302W, Iron losses, Pi = 16 w

All-day Output = (160 x 8) + (80 x 6) = 1,760 Wh

Pi for 24 hours = (16 x 24) = 384 Wh

Pc for 24 hours = $(160/08)^2$ X 302 X 8 + $(80/10)^2$ X 302 X 6 = 1677+201 =18783Wh

All-day input =All-day output + iron loss + copper loss =1760 + 3840 + 18783 =1817183Wh

Total power supplied in one year =1817183 X 365 = 663271 79Wh

Total cost@ is 380 Rs Per unit = Rs 252043282

(b) Full load output = 240VA, Full-load copper losses, Pc = 302W, Iron losses, Pi =16 W

All-day output = (160 x 8) + (80 x 6) =1,760 Wh

Pi for 24 hours = (16 x 24) =384 Wh

Pi for 24 hours reduced (1506%) = 384 – (384 X 1506%) = 3261 Wh

Pc for 24 hours =$(160/08)^2$ X 302 X 8 + $(80/10)^2$ X 302 X 6 = 1677+201 =18783 Wh

All-day input =All-day output + iron loss + copper loss = 1760 + 3261 + 18783 = 1,811393Wh

Total losses in one year = 1811393 X 365 = 661158 44Wh

Total cost@ is 380 Rs Per unit = 251240209 Rs

Total profit in one year =(25,20,43282 – 25,12,40209) = 803073Rs

12. Conclusion

After performing practical we found that eddy current loss is increasing in embedded core in comparison to non-Embedded core while hysteresis loss has been decreased by greater percentage in embedded core as compared to the non-Embedded core It can be concluded now that embedded core is more efficient than a non-Embedded core as iron loss has been reduced by (1506) %

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