American International Journal of Research in Science, Technology, Engineering & Mathematics

Available online at http://www.iasir.net

ISSN (Print): 2328-3491, ISSN (Online): 2328-3580, ISSN (CD-ROM): 2328-3629

AIJRSTEM is a refereed, indexed, peer-reviewed, multidisciplinary and open access journal published by International Association of Scientific Innovation and Research (IASIR), USA

(An Association Unifying the Sciences, Engineering, and Applied Research)

A Novel Technique for the Measurement of relative permeability of magnetic materials

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***Abstract**: The permeability of materials is very important in the electromagnetic and field of communication which is growing very fast today. This paper describes the novel techniques for the measurement of relative permeability of the magnetic materials. The two techniques for the measurement of relative permeability are described in detail and the results obtained by both methods are compared. The first measurement technique uses dc excitation to reduce excessive power loss and avoid damage of insulation of the windings. The second method required current clamp meter along with dc excitation for the measurement of relative permeability of the magnetic core. The both methods require less power and easy to determine relative permeability as compared to the other available methods based on ac excitation.*

***Keywords**: relative permeability, permeability, clamp meter, DC excitation, magnetic material*

I. Introduction

Permeability is the degree of magnetization that a material obtains in response to an applied magnetic field [1]. There are two basic types of magnetic materials: metallic and metallic Oxide. The most common metallic material is laminated steel which can be used in mains power transformers. This material works well at mains frequencies but rapidly becomes ineffective at high frequencies [2]. High permeability materials are very important in the electromagnetic based equipment. There are wide applications of magnetic material of suitable relative permeability. The magnetic material is used in heavy current engineering such as motors, generators, power transformers, level converters and embraces electromagnets. It can also be used for transducers core. The magnetic material is used also in information storage, it can store information quickly and reliably which has no need of continuous energy and can be reused as often as required [3]. Today the demand of communication field is growing fast and it required a material of suitable relative permeability. There are various techniques available for measurement of relative permeability. In ballistic method, a ballistic galvanometer is used. This method is used for the determination of B-H curve and hysteresis loop of ferromagnetic material. The disadvantage of this method is that it cannot measure directly the value of flux density corresponding to a particular value of magnetizing force but a change in flux density with change in magnetizing force [4, 5, 6]. Various types of permeameter are available for the measurement of permeability, used in magnetic testing are designed to avoid errors and difficulties of the simpler ring or test. The disadvantage of this method is to prepare a test specimen for the measurement of permeability and also leakage flux will be there. This paper describes two novel methods for the measurement of relative permeability of the magnetic material. Both methods are based on the dc excitation. It required comparatively less time for the measurement of relative permeability, also leakage flux in these methods is less. The first method describes the measurement of relative permeability of transformer core in which dc excitation is used for the purpose to saturate the transformer core comparatively at a lower value of current. It can be easily used in the laboratory. It also protect from damage of windings and insulation. The measurement will be simple and easily to determine the relative permeability of the transformers.

The second method requires only dc supply for the measurement of relative permeability. The specimen is made for this method is easy and simple. It requires a current clamp meter, a sheet of material of which the relative permeability is to be measured and an insulator. This method is safe and can be easily used in the laboratory. In this method, only battery supply is sufficient and no need of ac supply.

II. Proposed methods 1

The proposed method 1 discusses the measurement of relative permeability of a transformer core. DC excitation is used in this method to saturate the transformer core.

It may draw large inrush current when the iron core goes into deep saturation. The most important factors that determine the magnitude of the inrush current are winding resistance, an angle of energization, core residual flux, and the air-core inductance. Air-core inductance is the most important parameter needed for the accurate modelling of transformers involving deep saturation. However, it is not easy to measure in the field or laboratory because a very large ac power source (more than 10 times larger than the transformer rating) is needed. This is so because a high voltage is needed to push the core into saturation while it draws large currents when it saturates. In addition, the high voltage that is necessary to apply may damage the windings and the interlamination insulation [7, 8].
This proposed method requires low power to saturate the transformer core and the experiment can be carried out in the laboratory. Also, power loss will be less.

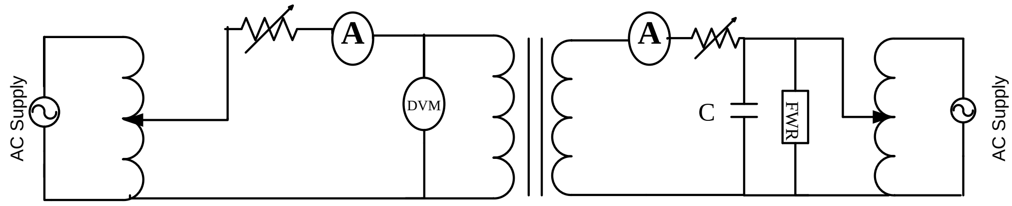

Fig 1: Circuit Diagram for the measurement of Relative Permeability of transformer core

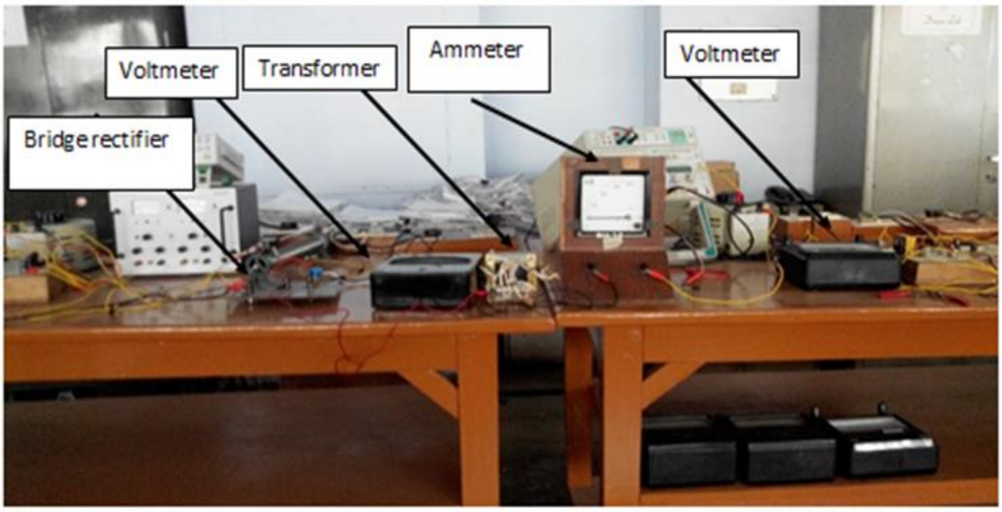

Fig 2: Experimental Setup for the Measurement of Relative Permeability of Transformer Core.

The Primary side of the transformer is connected to ac supply of 230V through autotransformer in series with variable resistance and ammeter. The ammeter reading is kept constant (say 50mA) as shown in figure 1.
The Secondary circuit is also connected to ac supply through autotransformer. A full bridge rectifier is connected across autotransformer and a parallel capacitor of 100 µF. Ammeter and variable resistance are connected in series. The experimental setup for the measurement of relative permeability of transformer core is shown in figure 2.
First of all ac supply is given to the primary and adjust autotransformer till ammeter reading is increased to 50 mA and kept constant. Now connect secondary side with ac supply. The bridge rectifier is used to convert ac to dc. This dc may contain harmonics which is eliminated by the capacitor connected in parallel. By varying the ac supply in the secondary side it can vary the ammeter reading. Now the ammeter reading gradually increases and measures the voltage across primary winding terminal voltage. The observations obtained by this experiment are shown in table 1. A dc supply is used to saturate the transformer core.

A. Formula Used

The relative permeability can be calculated using the following relationship as shown in table 2.

$$L = \frac{\mu_R \mu_O N^2 A_C}{l_C} \quad (1)$$

Where;
$\mu_o = 4\pi\times10^{-7}$ permeability of free space F/m.
μ_R = relative permeability

L= inductance of the core in H.
A_c = cross-sectional area of core m^2
l_C= mean length in meter.
R_{dc} =1.39 ohm
From equation (1) if inductance is known the relative permeability is calculated.

$$\mu_R = \frac{Llc}{\mu_O N^2 A_C} \quad (2)$$

Using the relations (1) & (2) we can say

$$\mu_R \propto L \quad (3)$$

Primary Current =50 mA (constant)

B. Observations and Results

Table 1: Observations for the measurement of relative permeability

Secondary side			Primary side	
Input AC voltage (V)	**DC Voltage (V)**	**Current (DC)**	**Terminal Voltage (V)**	**Supply Voltage(V)**
1.5	0.44	0.005	0.7	4.12
2.25	1.22	0.10	0.7	4.12
3.17	2.21	0.15	0.7	4.12
4.29	3.37	0.20	0.7	4.12
4.97	4.10	0.25	0.7	4.12
5.8	5.0	0.30	0.7	4.12
6.5	5.8	0.35	0.7	4.12
7.25	6.8	0.40	0.8	4.12
8.0	7.7	0.45	0.8	4.12
8.59	8.25	0.50	0.8	4.12
10.04	9.6	0.55	0.10	4.12
10.74	10.39	0.60	0.11	4.12
11.41	11.04	0.65	0.11	4.12
12.88	12.28	0.70	0.11	4.12
14.16	13.5	0.75	0.11	4.12

Table 2: Calculated Value of relative permeability

DC Current (Amp)	Impedance (Ohm)	X_L (Ohm)	L = $X_L/2\pi f$ (mH)	Relative Permeability (μ_R)
0.005	14	13.39	44.36	489.73
0.10	14	13.39	44.36	489.73
0.15	14	13.39	44.36	489.73
0.20	14	13.39	44.36	489.73
0.25	14	13.39	44.36	489.73
0.30	14	13.39	44.36	489.73
0.35	14	13.39	44.36	489.73
0.40	16	15.94	50.96	559.79
0.45	16	15.94	50.96	559.79
0.50	16	15.94	50.96	559.79
0.55	2	1.51	4.8	53
0.60	2.2	1.8	5.73	64
0.65	2.2	1.8	5.73	64
0.70	2.2	1.8	5.73	64
0.75	2.2	1.8	5.73	64

Variation of relative permeability with dc current is shown in figure 3. The value of relative permeability is initially constant for small value of dc current. When the transformer is saturated then the value of relative permeability is suddenly decreased.

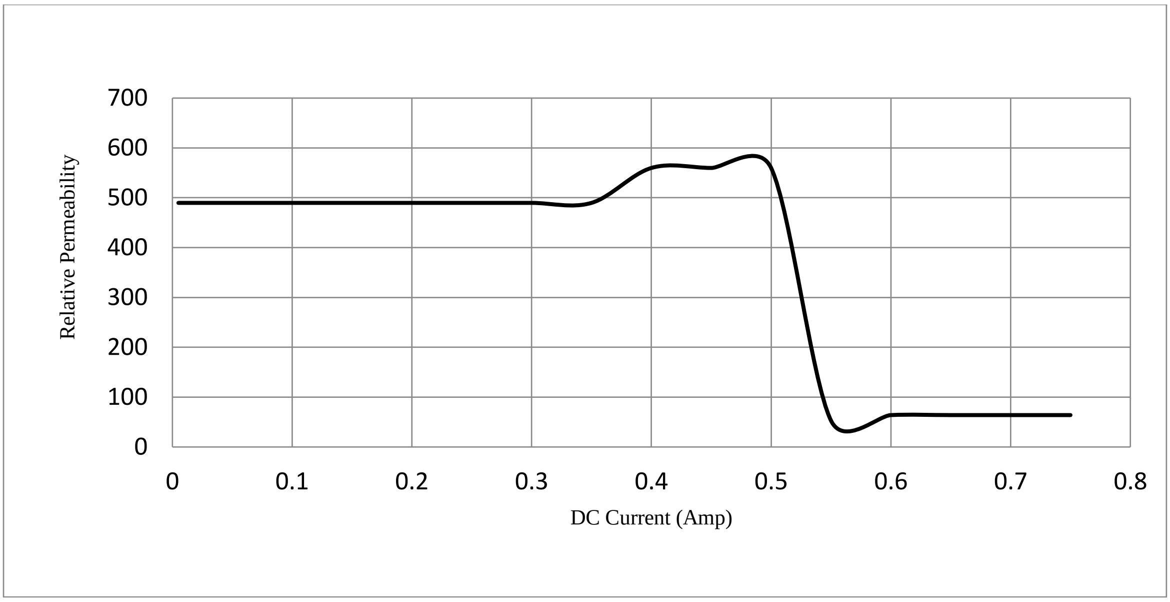

Fig 3: Variation of Relative Permeability with DC Current

III. Proposed Method 2

This technique requires current clamp meter for the measurement of relative permeability. The test specimen should be same as the size of the slot in the current clamp meter so that the test material is perfectly fitted in the slot. Here the dimension of the specimen is (6 X 8) mm. The paper insulator should be of the same dimension as a test material.

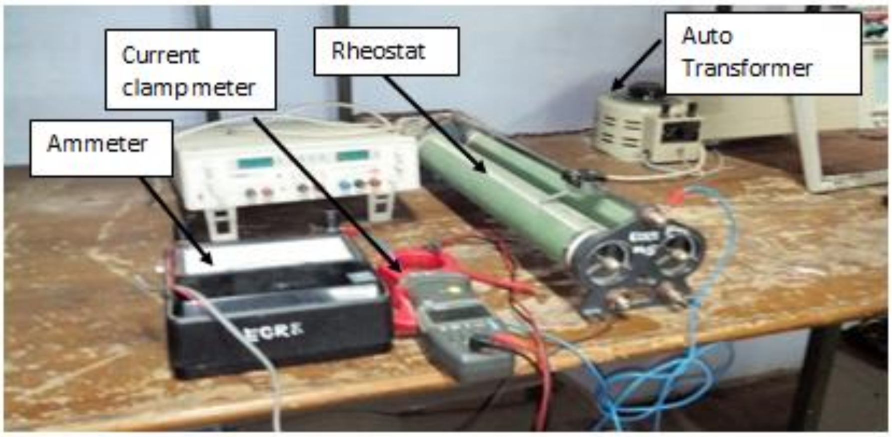

Fig.4: Experimental Setup for the Measurement of Relative Permeability Using Current Clamp Meter

The current is varied with help of rheostat and readings are taken with the test specimen fitted in the slot. The above observations are repeated while paper insulator fitted in the slot as shown in figure 4.

A. Formula used for calculation of relative permeability

Flux setup in the core: (i) without air gap

$$\emptyset_1 = \frac{\mu_0 NIA\mu_r}{l_c} \quad (4)$$

(ii) With air gap;

$$\emptyset_2 = \frac{\mu_0 NIA\mu_r}{\frac{l_c}{\mu_r}+lg} \quad (5)$$

(iii) With test core;

$$\emptyset_3 = \frac{\mu_0 NIA\mu_r}{\frac{l_c}{\mu_r}+\frac{l_{core}}{\mu_{core}}} \quad (6)$$

And also

$$\emptyset_1 \propto I_1 \quad (7)$$

$$\emptyset_2 \propto I_2 \quad (8)$$

And

$$\emptyset_3 \propto I_3 \quad (9)$$

From equations (4),(5),(6),(7),(8)&(9)

$$\frac{\emptyset_1}{\emptyset_2} = \frac{I_1}{I_2} = 1 + \frac{l_g}{l_c}\mu_r \quad (10)$$

$$\frac{\emptyset_2}{\emptyset_3} = \frac{I_2}{I_3} = \frac{\frac{l_c}{\mu_r} + \frac{l_{core}}{\mu_{rcore}}}{\frac{l_c}{\mu_r} + l_g} \quad (11)$$

Here l_g and l_{core} are the thickness of insulating material and a test sample of the magnetic material respectively, which is equal to 0.48 mm.
And lc = Mean length of clamp meter is equal to 0.471 m.
Ac is an area of clamp meter.
μ_{rcore} can be easily calculated from equation (11) as shown in table 3

***B.* Results Using Clamp Meter**

Current (amp) I_{dc}	Reading with insulator I_2 (amp)	Reading with Core I_3 (amp)	Relative permeability
3	2.58	2.99	480
5	4.35	4.96	395

Table 3: Relative Permeability Measured By Current Clamp Meter

IV. Conclusions

This paper describes the novel techniques for the measurement of relative permeability of the magnetic materials. From the results obtained from the method 1 and method 2, it can be easily seen that the relative permeability is approximately same as 489 & 480. These methods can be used for the measurement of relative permeability of magnetic core in the laboratory. Reading may be deviated from actual values as during the experimentation. These errors are minimized if benchmark instruments are used.

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Acknowledgments

We take this opportunity to thanks Professor M.S. Jamil Asghar, Department of Electrical Engineering, Aligarh Muslim University, Aligarh for valuable guidance and for providing all the necessary facilities, which were essential in completion of this work.

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