KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
ELECTRICAL ENGINEERING DEPARTMENT
EE-462 ELECTRICAL MACHINES

Term: 012

Experiment # 1
SEPARATION OF HYSTERESIS AND EDDY CURRENT LOSSES IN SINGLE PHASE TRANSFORMERS

INTRODUCTION

The core losses caused by the alternating magnetic flux may be subdivided into hysteresis and eddy current losses. The hysteresis loss is given by the Steinmetz formula

$$P_h = K_h B_m^X f \qquad \text{… eqn.1}$$

where K_h = a constant which depends on the core material,
f = frequency in cps,
B_m = maximum flux density in the core in Wb/m^2, and
X = Steinmetz exponent which varies from 1.6 to 2.5.

The eddy current loss, which is due to the time varying flux, can be minimized by using laminations. An expression for this loss is given by

$$P_e = K_e B_m^2 t^2 f^2 \qquad \text{… eqn.2}$$

where K_e = a constant dependent on the core material and
t = thickness of lamination.

Decomposition of the measured core loss into its hysteresis and eddy current components is necessary to define detailed magnetic properties of ferromagnetic cores.

THEORY

The core losses are given as $P_{ir} = P_e + P_h = K_e B_m^2 t^2 f^2 + K_h B_m^X f$ … eqn. 3.

In order to determine P_e and P_h separately, the core loss (of the given transformer) is to be measured at different frequencies while keeping B_m =constant that implies

$$P_{ir} = K_e' f^2 + K_h' f \quad \text{or} \quad \frac{P_{ir}}{f} = K_e' f + K_h' \qquad \text{…. eqn. 4.}$$

Equation 4, which relates $\frac{P_{ir}}{f}$ to the frequency f, represents an equation of a straight line intersecting the axis of $\frac{P_{ir}}{f}$ at K_h' and of slope K_e'. Thus, plotting the relation $\frac{P_{ir}}{f}$ against f determines K_h' and K_e' (shown in figure 1). The flux density B_m can be kept constant at different frequencies by having $\frac{V}{f}$ constant where V is the voltage applied to the test transformer, which is given by

$$V \cong E = 4.44\, fNAB_m \qquad \text{…. eqn. 5,}$$

where E = induced emf (rms value),
N =the number of turns of the exciting winding, and
A = cross-sectional area of the core.

Therefore, if $\frac{V}{f}$ is kept constant, B_m will remain constant. Thus feeding the transformer with different frequencies make it necessary to vary the applied voltage at each frequency so as to have $\frac{V}{f} = \frac{V_{nom}}{f_{nom}}$. In order to fulfill the above requirements of feeding the transformer, the later is supplied from an alternator whose excitation is kept constant. For such alternator, we have $V = \frac{k\varphi}{P}$ and $f = \frac{Pn}{60}$ thus $\frac{V}{f} = \frac{60k\varphi}{P} = k\varphi$. If the excitation of the alternator is constant, its output voltage is proportional to the frequency i.e. $\frac{V}{f}$=constant.

EXPERIMENT

OBJECTIVE

To measure the core loss at varying frequency and hence separate the hysteresis and eddy current components.

PROCEDURE

1. Connect the transformer as for no-load test with its terminals connected to the output terminals of the alternator, which is driven by dc motor (as shown in figure 2).
2. Adjust the field current of the alternator so that it gives an output voltage V and frequency f at rated speed equal to the nominal voltage V_{nom} and frequency f_{nom} of the transformer and then keep this value of I_{fg} constant all over the test.
3. Vary the speed of the alternator in steps by varying the speed of the driving motor and take readings of W_0, A_0, V_0, and f for each value of the speed.
4. Measure the transformer primary dc resistance r_1 by the volt-ampere method.
5. Calculate P_{ir} for each speed from

$$P_0 = I_0^2 r_1 + P_{ir} \qquad \text{…eqn.6.}$$

6. Plot a curve of $\frac{P_{ir}}{f}$ against f and then obtain the eddy and hysteresis losses at the rated voltage and frequency.
7. Repeat the above steps for a value of $\frac{V}{f}$ equal half the value chosen in step#2.
8. Calculate the exponent X of equation 1: $P_h = K_h B_m^X f$. We have $B = B_{nom}$ at $\frac{V}{f} = \frac{V_{nom}}{f_{nom}}$ and $B = 0.5B_{nom}$ at $\frac{V}{f} = 0.5\frac{V_{nom}}{f_{nom}}$. If P_{h1} corresponds to B_{nom} and P_{h2} corresponds to

$0.5.B_{nom}$ at rated frequency, then, $\dfrac{P_{h1}}{P_{h2}} = \dfrac{K_h\, f\, B_{nom}^X}{K_h\, f\, 0.5^X\, B_{nom}^X}$ or $\ln \dfrac{P_{h1}}{P_{h2}} = X \ln 2$, hence,

$$X = \frac{\ln \dfrac{P_{h1}}{P_{h2}}}{\ln 2} \qquad \dots \text{ eqn.7.}$$

Equation 7 determines the Steinmetz exponent for the test core material.

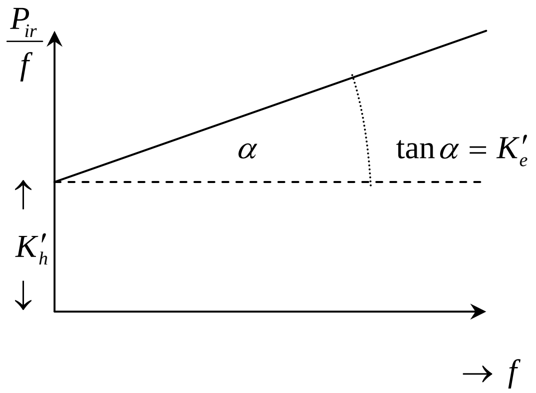

Figure 1. Plot of $\dfrac{P_{ir}}{f}$ versus f

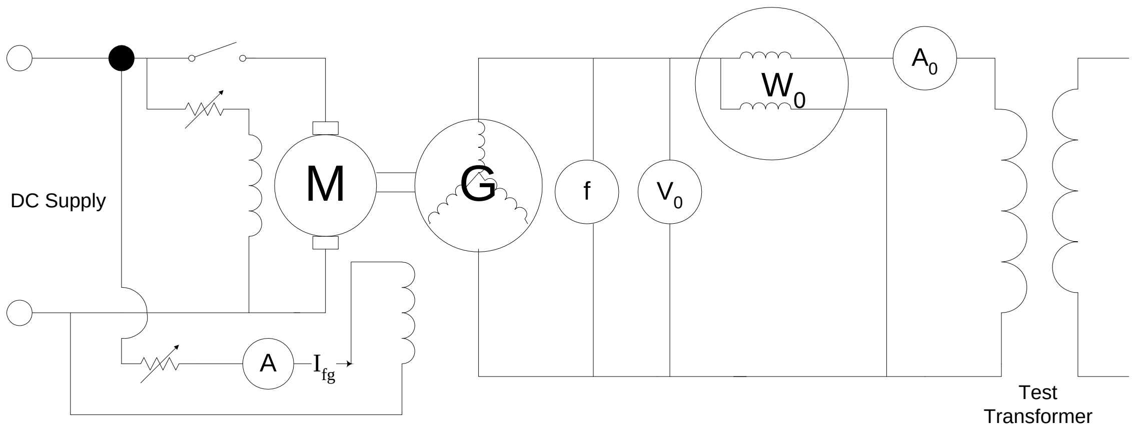

Figure 2. Experimental setup