PHENIX TECHNOLOGIES
An overview of Motor Core Loss Testing [Version 1.0A]
By Paul Winter
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INTRODUCTION

Continually rising utility rates and the enforcement of power factor penalty clauses make it more important than ever that rewound motors maintain the optimum level of efficiency and performance.

The largest single factor in determining whether a motor will continue to operate at rated efficiency is the condition of the core steel.

Besides affecting efficiency, a damaged core will result in higher operating temperatures for the repaired motor. If the temperature is increased by 7°C, the insulation life falls to 62% of its design value . If the increase is of 14°C, the insulation life falls to 38% of its design value. These temperature increases are not unusual when core losses increase. As you know, one of the major causes of motor failure is insulation breakdown.

Another problem that results from higher operating temperatures and leads to increased costs is that grease life is diminished. If the temperature is increased by 7°C, grease life falls by 15%. With an increase is of 14°C grease life falls by 31%. This means that your customer must change his regreasing schedule or run the risk of bearing failure, another major cause of motor downtime.

The quality of the core iron is probably the biggest question mark surrounding a rewound motor. Your customer can get a new winding, an insulation system as good or better than the original, and new bearings, but even the best rewind is subject to failure if the iron is bad. Core loss testing can remove much of this uncertainty.

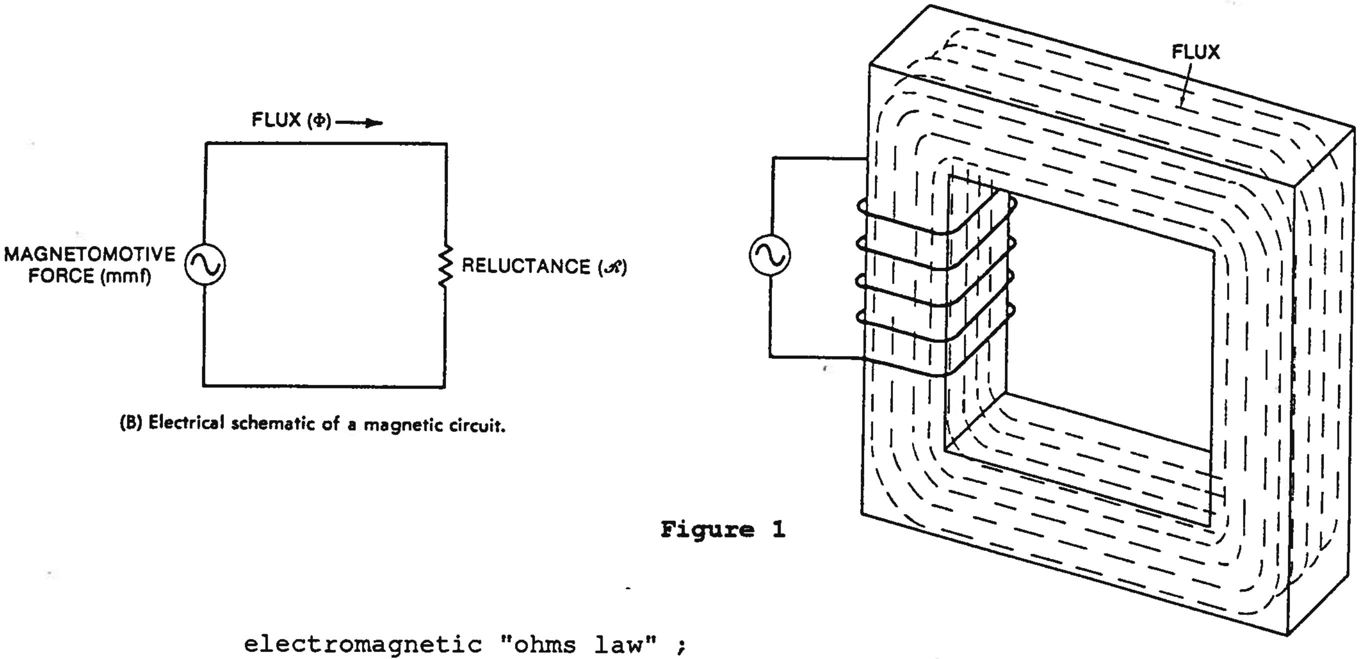
Before we get into an explanation of core loss testing we must point out that the magnetic flux paths introduced by the Core Loss Test Set into the stator or rotor under test are not meant to simulate the actual lines of flux that the motor experiences under actual running conditions. For example,a rotor core loss varies with rotor frequency, and hence with the slip. Under running conditions the slip is only about 0.03, the rotor frequency is only about 2 Hz, and the rotor core loss is negligible. At starting, and during acceleration, however, the rotor core loss is high and decreasing (the friction and windage start at zero and increase). When performing a core loss test the rotor or stator under test is treated as a transformer with the output power cable of the core loss test set acting as a single turn primary or excitation winding.

Acting as a transformer core, the rotor or stator are subject to, and therefore, must operate within the same constraints as a transformer core.

The following sections give a basic theory of magnetic circuits and basic transformer design relevant to the understanding of core loss testing.

THE MAGNETIC CIRCUIT

The operation of the magnetic circuit may be compared to that of the electrical circuit. The ampere-turns ($I \times N$), which is also called the magneto motive force, is analogous to voltage. A poor conductor of flux has a high magnetic resistance, appropriately named *reluctance* ($\Re$). The greater the reluctance, the higher the magneto motive force required to obtain a given flow of flux.



(B) Electrical schematic of a magnetic circuit.

Figure 1

(A) An iron flux "circuit."

electromagnetic "ohms law" ;

$\Re$ = RELUCTANCE

ϕ = FLUX

mmf = MAGNETO MOTIVE FORCE

$$\phi = \text{mmf} \div \Re$$

The reluctance of a core depends on the composition of the metal and its physical dimensions, in exactly the same way that the electrical resistance of a conductor is related to its length (l), cross-sectional area (a), and its specific resistance (p) which is the resistance per unit length.

In order to establish the magnetic flux in the core it is necessary to supply a magnetizing current to the primary winding. The magnitude of the magnetizing current is governed by the reactance of the primary winding. This reactance, of course, depends on the inductance and frequency. The inductance in turn depends on the permeability of the core at a given flux density and frequency.

As the flux density is increased into saturation, the permeability drops and the magnetizing current increases much more than proportionally to the increase in flux density. Since the flux density is proportional to voltage, a plot of magnetizing current against voltage has the same shape as the saturation curve previously shown.

The loss current and magnetizing current together make up the total no-load current. The loss current is a power component of the total current, while the magnetizing current is not. In other words the two components are not in phase. It is necessary to add them vectorally rather than arithmetically. thus;

$$Io = \sqrt{(Im^2 + Il^2)}$$

The volt-amperes required to establish the reactive magnetizing current is sometimes referred to as the *apparent loss* because in itself it does not represent a real loss in power-consuming watts.

LOSSES IN GENERAL

The average input power to a machine or transformer is always greater than the average output power, because some of the energy is converted into heat through several physical phenomena occurring naturally inside the device. For example the I^2R losses in the windings or friction in the bearings of the machine. Additional losses are due to windage and ventilation and to the effects of alternating magnetic fields.

These losses may be grouped into two categories, **constant losses** and **load-dependent losses.**
The principal **load-dependent losses** are the I^2R loss in the armature and other windings. In addition, the stray magnetic fields caused by the load current induce eddy-current losses in the windings and in adjacent metal components.

The **constant losses** include;
(1) Bearing friction.
(2) Brush friction and windage.

and the following, which are of interest in the discussion of core loss testing.

(3) *Hysteresis loss in the iron core.*
(4) *Eddy current losses in the iron core.*

PROPERTIES OF CORE MATERIALS

Generally speaking, there are five properties to be considered in core materials. These are;

(1) **Permeability.**
(2) **Saturation.**
(3) **Electrical resistivity.**
(4) Remanence.*
(5) Coercivity. *

*Remanence and coercivity together comprise the term **hysteresis.**

Permeability (μ)

In general, permeability is the ability of a core to conduct flux. In mathematically it is the ratio of flux density (B) to the magnetizing force (H).

$$\mu = B \div H$$

When B is plotted against H a curve is obtained which is called the saturation curve. The slope of this curve at any given point gives the permeability at that point. The permeability curve, when plotted, is seen to be not constant It's value can only be stated at a given value of B or H.

Saturation

This property is also displayed in the saturation curve. It can be seen that beyond a certain value of H there is little increase in B; the iron is approaching saturation. Different materials saturate at different values of flux density. Note that at saturation the permeability must be small or zero because there is little or no increase in B for an increase in H. This means that the inductance is very small when the iron is taken into saturation.

Electrical Resistivity

The alternating core flux induces voltages in the core itself. These voltages cause ***eddy currents*** , which are perpendicular to the flux path, to circulate in the core, thus wasting power. If the electrical resistance of the core is high, the currents will be low; therefore a feature of low-loss material is high electrical resistance. This type of loss is reduced by building the core with thin laminations, each being insulated from the others. The insulation between the laminations restricts the flow of eddy currents and greatly reduces the eddy current loss. This insulation may be a special coating on the individual laminations or it may be the natural iron oxide layer formed during the heat treatment of the core material. Heat treatment is necessary to produce the desired mechanical and magnetic properties.

Hysteresis (Remanence and Coercivity)

When an initially demagnetized sample of material is taken through a complete cycle of magnetization and B plotted against H , a figure such as shown in figure 3 results. Please note that this is also a "saturation curve" as shown in figure 2. The difference is that in figure 2 the material was taken through a quarter cycle only, while figure 3 is a picture of the complete cycle which follows the first quarter cycle. The first cycle is shown as a dotted line. Here the curve starts at zero. As H is increased, the flux density B increases along the dotted line to the saturation point S. When H is now decreased and B plotted, the curve is found to follow a path such as SR; it does not return along the original path OS. From figure 3 it can be seen that when H has been reduced to zero the core is still magnetized and a value R of flux density still remains in the sample. This amount of R is appropriately called the *Remanence*.

The magnetizing force H is now reversed in polarity to give negative values. These are progressively increased and the curve continues from R to C. At point C the flux density is once more at zero but H has a specific value. This value (OC) is the *coercivity;* it is the amount of magnetizing force needed to force (coerce) the flux density back to zero. As H is taken through the remainder of the cycle the curve continues to S, then to R, then C, and back again to S.

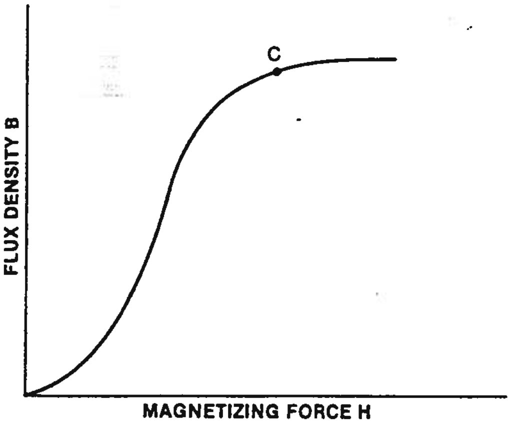


Figure 2

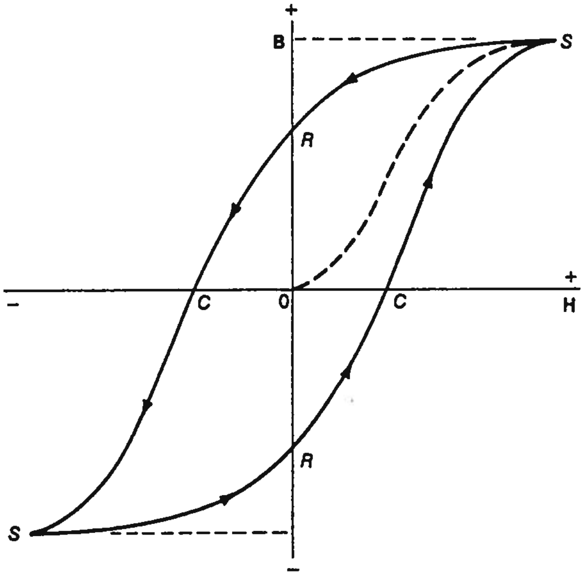


Figure 3

This hysteresis loop represents energy lost in the core, a kind of magnetic friction, which is in addition to the eddy current losses The area of this curve is the joules of energy lost per cycle of flux oscillation per volume of material. Thus the hysteresis loss depends on the peak flux density in the iron ,the frequency of the flux oscillation, and the amount of material.

CORE LOSS PRINCIPLES

The basic transformer design formula which is used is

$$V = 4FfaBN^{*}\ 10^{-8}$$

Where;

V = the voltage across the considered winding.
F = the form factor.
f = the input frequency in hertz.
a = the cross-sectional area of the core in square inches.
B = the flux density in lines per square inch.
N = the number of turns on a considered winding.

When performing transformer calculations an important consideration is the waveshape of the power source. This is taken into account in the above formula by F which is called the form factor This number is a comparison of the RMS value of the waveshape to the average value of the waveshape and is represented mathematically as;

$$F = \text{RMS value} \div \text{average value.}$$

A sinewave has an RMS value of 0.707 and an average value of 0.637. Thus;

$$F = 0.707/\ 0.637 = 1.11$$

From this it can be seen that it is important to the accuracy of the calculation that a non-distorted sinewave be used.

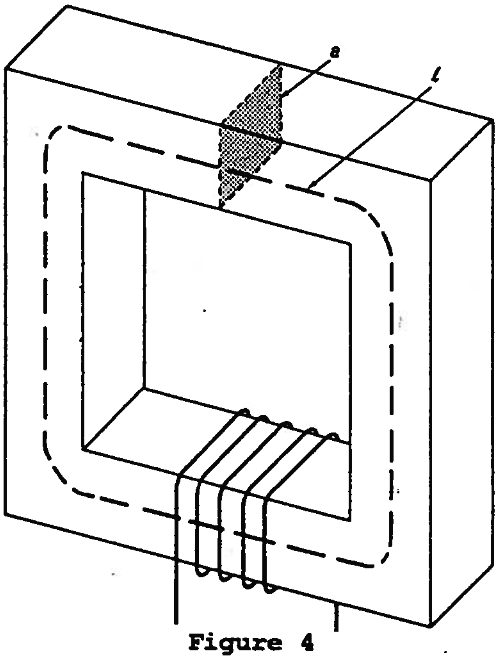


Figure 4

The cross-sectional area [a](see figure 4) can be thought of as the conductor area for the lines of flux. When we say that we are exciting the core to 85 kilolines, for example, what we are actually saying is 85 kilolines per square inch. It is this area that we are referring to.

Often the above formula is encountered with a stacking factor included. The purpose of the stacking factor is to compensate for the fact that the measured area of the core is always bigger than the actual area of iron. This is due to the spacing between the laminations.

The flux density is usually given in kilolines (thousands). For more on this refer to the previous discussion of the magnetic circuit.

CORE LOSS TEST

With respect to our discussion of core loss testing the above formula is arranged to solve for the voltage [V] necessary to excite the unit to the number of kilolines required. The default value is 85 kilolines in the PHENIX TECHNOLOGIES software package. This number may be changed by the user.

The Form Factor is set internally to the software to 1.11 which corresponds to a sinewave. All PHENIX TECHNOLOGIES coreloss sets feature a sinewave output to guarantee the highest accuracy possible.

The frequency [f] is preset to 60 Hz being representative of the power source for the Core Loss Test Set. Note that this may be changed to 50 Hz by the operator in the Setup Menu if required.

The number of turns [N] is set internally to the software to 1 which represents the output power cable of the Core Loss Test Set.

When a coreloss test is performed the physical dimensions of the unit (rotor or stator) are needed.From this data the *cross-sectional area,* [a] is determined. Along with this the *total volume of steel* is calculated. The reason for calculating this value will be addressed shortly.

The software calculates the voltage necessary to excite the unit to the specified number of kilolines. When this is attained, as read on the output voltmeter, the coreloss set measures the output current level, which is as you recall, the vector sum of the loss current and magnetizing current.

The actual voltage that the unit is excited to is measured on the output voltmeter. By rearranging the above formula, the software then recalculates the actual kilolines that the unit is exited to. If the voltage on the output voltmeter is the same as the calculated value the kilolines will agree. If the output voltage is lower than the calculated value then the kilolines will less. If the output voltage is higher than the calculated value then the kilolines will be greater.

The wattage is measured on the wattmeter.

By multiplying the Output voltage by the Output current the *apparent loss* is calculated. This apparent power is then compared to the real loss, or true power consumption as measured by the wattmeter. The power factor is attained;

PF = Wattage ÷ Apparent loss

The wattage cannot exceed the apparent power, therefore, this value will never be greater than 1. A value approaching 1 indicates that the hysteresis and eddy current losses are becoming larger as compared to the reactive power.

Most standard lamination steel weighs in at about 0.276 lbs. per cubic inch. When this is multiplied by the *total volume of steel* the weight of the unit core can be calculated. This is compared to the wattage as watts per pound. Obviously the lower this value is the better.

The last measurement is called the ampere-turns per inch. This value is a comparison of the output current to the mean magnetic path length. As you will recall from our discussion, the amperes * the number of turns is equal to the magneto motive force(mmf). Since our turns are equal to 1, our magneto motive force is equal, essentially, to the output current.

Therefore;

H = Output current ÷ mean magnetic path length.

H is then the magnetizing force required to excite the rotor or stator under test to the desired flux density. The greater the value of H, therefore, the greater the reluctance, and the lower the permeability. Hence, the lower this value, the better the unit under test.

LOOP TEST

The core loss test as described in the EASA manual describes a procedure which is essentially performing the above equation. We have included this description to indicate to the reader the similarities as well as the differences between these two methods.

The first portion directs to calculate the cross-sectional area, which is multiplied by 0.80 to take into account the stacking factor.

The core area is then multiplied by the value of 0.26. If we look at the voltage formula again,for the present omitting N (number of turns) we find;

$$V = 4FfaB^{*}\ 10^{-8}$$

$$V = 4 \times 1.11 \times 60 \times 85000 \times 10^{-8} \quad = 0.22644$$

which is roughly the same number. The volts per turn are then calculated by introducing the cross-sectional area [a] into the formula.

This method of testing assumes a fixed power source,therefore,the supply voltage is divided by the volts per turn which calculates the number of turns [n] which are needed.

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