Technical Bulletin CORE LOSS TESTING THEORY

CORE LOSS TESTING IN THE PRACTICAL MOTOR REPAIR ENVIRONMENT

ABSTRACT

LEXSECO developed the first commercial Core Loss Tester over thirty five years ago. Since inception, LEXSCO has performed core loss tests in a variety motor repair shop environments. Thousands of LEXSECO testers are in use around the world. This publication will present the mathematical foundations of the toroidal transformer type core loss test and discuss the application of this test procedure to the motor repair environment including common core repair techniques.

INTRODUCTION TO LOSSES

Before any test procedure for determining core losses and core degradation can be explained, the nature of steel properties should be understood. Ferrous materials have various electrical, magnetic and mechanical properties that are taken into consideration during the design of an electrical apparatus. The object of the design is typically to maximize output while minimizing the associated electrical and mechanical losses. By design, the motor is known to have a certain level of I^2R copper loss, windage and friction, and stray load losses which accompany the specific design parameters of the motor. Similarly designers choose the grade of core steel, the designed thickness of the steel and the processing techniques in an attempt to minimize the steel losses without incurring a substantial increase in material costs. These losses are divided into two categories:

1. Hysteresis losses
2. Eddy current losses

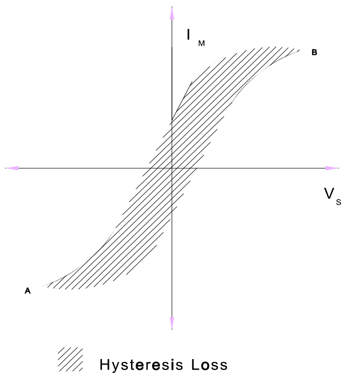


Figure 1 - Hysteresis Loss Curve

Hysteresis loss is the amount of input energy expended to change the magnetic polarity of the steel in conjunction with the changing polarity of the alternating current waveform. This portion of the total core loss is represented by the shaded portion of the hysteresis curve shown in Figure 1. Ideally, the voltage (V_S) to magnetization current (I_M) graph would be represented by a single path from A to B equal to the path from B to A. However, due to this increase in expended energy, the path from A to B is not equal to the path from B to A, and a hysteresis loop is developed. The area between the two paths is identically equal to the hysteresis loss. Hysteresis loss will be dissipated in the form of heat.

Eddy currents are circulating currents resulting from the magnetic fields generated in the electric motor. Normal eddy current flow is shown in Figure 2.

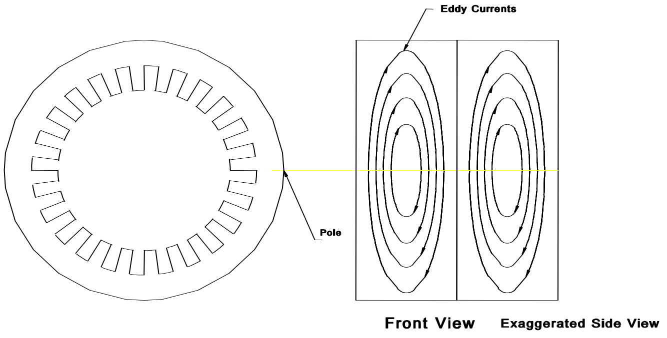


Figure 2 - Normal Eddy Current Flow

When any electrical conductor is placed within a magnetic field, a current proportional to the cross-section of the conductor and the strength of the field is known to flow perpendicular to that field. For this reason, steel lamination thickness is minimized to reduce the amount of eddy current flow.

When the insulation between laminations breaks down, there is an associated increase in the eddy current flow. At the point of degradation, currents flow between the laminations as shown in Figure 3. Eddy current loss is the total input power lost to these circulating currents. Like hysteresis loss, eddy current losses are dissipated in the form of heat.

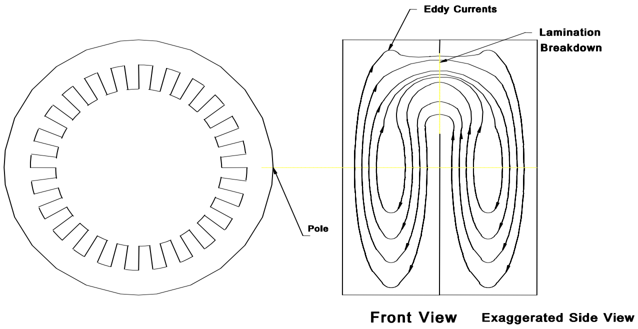


Figure 3 - Interlaminar Eddy Current Flow

Summing the eddy current and hysteresis losses will provide the total core losses for any given motor.

CORE LOSS TEST PROCEDURES

Today, there exists two types of tests for determining the total core loss of an electric motor. The first of these is known as the segregated loss method described in the Institute of Electrical and Electronics Engineers (IEEE) Standard 112 and the Canadian Standards Association Standard 390. Using linear regression analysis and various percentage loading characteristics, this test method determines each component of the total losses as well as the subject motor efficiency. When the exact nature of core losses in the complete motor system are required, this type of test is much more effective than any other test of its type. However, the subject motor must be in complete working order. This limits its usage to motor repairs which can be classified as preventative maintenance repairs. Second, the testing procedure must be performed in laboratory controlled environments. Subletting core loss testing to laboratories specifically devoted to motor testing is a costly and time consuming venture. Conservative estimates of the time and cost of segregated loss testing is approximately one day per motor at upwards of $1000 per day. This further reduces the set of motors to non-emergency breakdowns. Obviously, for the motor repair industry, the segregated loss method for determining the condition of the core is very impractical.

The other method, which is well suited to the motor repair industry, is commonly referred to as the Toroidal Transformer Test, or loop test, as shown in Figure 4.

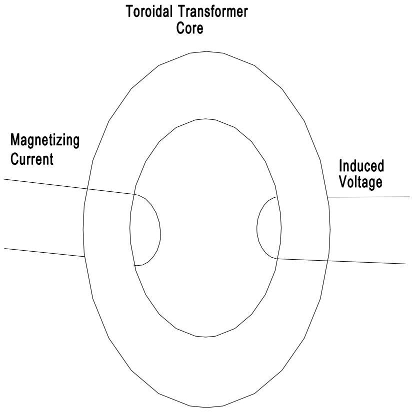


Figure 4 - Toroidal Transormer Test

While there exist several variations on the toroidal transformer test procedure, they all share the same basic mathematical foundations. The principles underlying the traditional “loop test,” and the commercial Core Loss Tester, are based upon an electromagnetic equation known as Faraday’s Law. This application of Faraday’s Law (1) holds that any laminated steel core assembly, regardless of size or design, can be used as the core of a toroidal transformer. Once excited to a selected backiron flux density, the power lost to the core steel can be measured. More specifically,

$$v = n(\frac{d\emptyset}{dt}) \qquad (1)$$

Where v is the induced voltage, n is the number of turns in the transformer and Ø is the flux in the core. Given that

$$\emptyset = B_M \times c \qquad (2)$$

where B_M is the flux density and c is the cross-sectional area of the toroid, we can directly incorporate the flux density (2) into Faraday's Equation (3).

$$v = n\left(\frac{d(B_M \times c)}{dt}\right) \qquad (3)$$

With the loop test, the voltage (v) in Faraday's Equation is held constant at the value supplied by the fixed power source. With a known target back iron flux density (B_M), this equation can be solved for the number of turns (n). By wrapping the calculated number of turns around the core, the target flux density is achieved. Being both labor intensive and applicable to only stator cores, the loop test is often omitted from the repair procedure of most repair shops.

For the commercial core loss tester, the number of turns (n) is held constant at one turn and the voltage source is varied. This achieves the same goal while simplifying the test procedure.

To further enhance the accuracy of the test flux density level, the equation can be further simplified to solve for the flux (Ø) instead of the voltage (v). This solution, while proprietary to IRD LLC, is both waveshape and frequency independent, thus removing the effects of inherent transformer harmonics from the equation.

Once the target back iron flux density has been reached, the excitation current, induced voltage and the excitation and resultant power levels are measured. By taking the difference between the excitation power on the primary and the resultant power on the secondary of the toroidal transformer, the loss to the core steel is determined. Copper loss to the transformer winding is assumed negligible due to the size of the conductor used.

APPLYING THE CORE LOSS TEST

While the theory behind the toroidal transformer test is relatively simple, the application of the theory to various motor designs is complicated and requires further explanation.

The watts loss is divided by the weight of the steel to yield an industry accepted standard value of watts-per-pound (kilogram). This value removes one of the remaining variables in the cores under test which is the size of the core. Now, a 500 HP stator core with a known watt loss can be compared to that of a 5 HP stator.

Key to evaluating the results of core loss testing is taking a large random sample of stator core tests. With the aid of statistical analysis, the average core loss and distinct marginal and maximum rejection limits can be calculated. The average core loss (ẋ) is given by

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (4)$$

and the standard deviation (σ) of the statistical population is defined as

$$\sigma = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n} \qquad (5)$$

After careful examination of the graphical results, it is seen that the lower limit (L_1) can be equated as

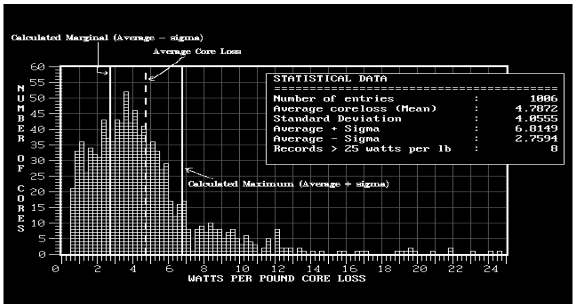
$$L_1 = \bar{x} - \frac{\sigma}{2} \qquad (6)$$

and the upper limit (L_2) can be equated as

$$L_2 = \bar{x} + \frac{\sigma}{2} \qquad (7)$$

Assuming that the average stator core is marginal and would require some repair, the three bands created by the addition of the lower and upper limits can now be classified. Motor cores in the region defined from 0 watts-per-pound to the lower limit (L_1), named the marginal limit, are classified as good stator cores requiring little or no repair. From the marginal limit to the upper limit (L_2), named the maximum limit, are marginal cores requiring more extensive repairs. The outer band, with watts-per-pound greater than the maximum limit, is considered to contain bad cores. These cores are usually known to have significant damage to the core iron and interlaminar insulation system and cannot always be satisfactorily repaired.

As with any statistical calculation, the size of the sample (n) determines the accuracy or the confidence level of the calculations. As sample statistical population (n = 1006) is shown is Figure 5.



```
STATISTICAL DATA
========================================
Number of entries             :     1006
Average coreloss (Mean)       :   4.7872
Standard Deviation            :   4.0555
Average + Sigma               :   6.8149
Average - Sigma               :   2.7594
Records > 25 watts per lb     :        8
```

Figure 5 - Sample Watts per lb Statistical Population

The second key realization is that these rejection limits are dynamic. Original-NEMA frame motors, constructed of thicker laminations and lower grades of core steel, have an average core loss greater than the maximum rejection limit of the T-Frame motor, regardless of horsepower. Since Original-NEMA frames have been replaced by U-Frames and subsequently by T-Frames, whose averages are respectively 25% and 50% less than Original-NEMA, the general test average has trended downward. For this reason, test comparisons should be performed against a sample of similar motors, and hence the creation of multi-parameter testing.

In multi-parameter testing, distinct marginal and maximum rejection limits for each of the various frame classifications (including Pre-NEMA, Original-NEMA, T-Frame, U-Frame, High Efficiency, Above-NEMA and IEC frames) are generated. This insures that the subject test core is being compared to cores of similar type and design. With the Above-NEMA frames, making a similar comparison requires that the nameplate rated efficiency and the manufacture date be within the same period. Similarly, a statistical sample of nearly identical special purpose motors must be made to provide any useful information regarding the condition of the core steel.

Collecting a sample population large enough to perform statistical analysis is not an easy task. A single motor shop assembling data may spend a year or more before achieving any level of confidence. To expedite this procedure, the results obtained by more than one motor repair facility should be collected. If statistically analyzed on regular basis, this information will dynamically track the trends in the motor industry. The introduction of a new motor frame into the industrial sector can be easily analyzed and incorporated into the multi-parameter testing environment in a relatively short amount of time.

BEYOND STATOR TESTING

One distinct advantage of the commercial core loss tester over the multiple turn loop test is the ability to achieve excitation in the rotating member of both AC (wound and squirrel cage rotors) and DC (armatures) machines. For wound rotors and armatures, the methods already described are easily adapted. For squirrel cage rotors, however, a slightly different approach must be adopted. Except during startup, or in the instance of variable speed applications such as wound rotor motors or inverter duty, the frequency in a squirrel cage rotor approaches zero as the machine approaches synchronous speed. Provided the rotor is operating at nearly full speed and does not experience frequent start/stops, rotor losses caused solely by steel degradation can usually be ignored. For those rotors excluded in the above description, the answers provided by testing rotors for losses, bar/endring integrity and hot spots can be quite helpful in determining the operational integrity of almost any rotor, but the watts-per-pound calculation can be ignored. Because the rotor is not typically driven by a 60 Hz AC waveform as supplied by the core loss tester, the losses determined by the 60 Hz test will contain hysteresis and eddy components that are greatly amplified from the original design criterion.

REPAIR OR REPLACE?

Once a core loss test has been performed, and the damaged core steel areas have been identified, they must be repaired, the core must be restacked, or the core must be replaced. From an economic standpoint, this decision must be made with both the repair facility's and the end user's best interests in mind. Specialty stator cores and above 50 horsepower stator cores can usually be repaired and rewound for considerably less than the replacement core cost. Below 50 horsepower, however, it is usually more cost effective for the end user to replace the motor than repair/rewind the core.

Beyond the economic factors, rewinding a damaged stator core with satisfactory results depends on the repair techniques used. The following list of common repair techniques are provided, but are by no means exclusive. Without exception, the object of the repair is the reduction or elimination of the damaged areas while minimizing the deformation of the core steel.

CRACKING: (Also referred to as bumping or pounding) Of the most common repair practices for reducing watts-per-pound loss and clearing hot spot areas, cracking will usually provide the best results without removing core iron or deforming the core.

Since the process can be performed in a relatively short period of time with standard shop tools, it should be preformed before attempting any other techniques. This technique may be applied to the stator, would rotor or armature. By striking the back iron section of the outside lamination with a mallet (or hit pin and hammer), the shorted laminations will vibrate and often separate.

SPREADING: Like cracking, this technique does not remove steel from the test core, but it does require that the laminations be spread apart. In many cases, spreading of the laminations can clear up hot spot areas which remain after cracking. Using a screwdriver or similar tool and dragging the surface of the affected tooth area will provide sufficient interlaminar separation for insulation to be applied.

GRINDING: Grinding is typically used to remove shorted iron caused by mechanical failures (i.e. copper blown in the slot or rotor dragging the stator tooth surface). When handled properly, areas can be cleared without the removal of excessive amounts of steel. Filing or grinding the affected areas may produce a significant reduction in the watts-per-pound.

Once the desired results have been achieved, the final and most critical step in the repair process is reinsulating the core. When the improvement in core condition is substantial enough to warrant the rewind of the core, the core stack must be reinsulated to prevent the return of the damaged areas. The core should be returned to its original form before the rewind. An optional step in this procedure is a final core loss test to verify that the core condition has not returned to its original state (some change is acceptable).

CONCLUSIONS

Several methods for determining the core losses in an electric motor exist and each has it advantages and disadvantages over its counterparts.

When utilized properly, the commercial core loss tester is effective for determining the condition of motor core steel in a practical motor repair environment. Combined with an aggressive data collection and evaluation strategy and the proper repair techniques, it can adapt to changing motor designs and insure that the repaired motor, which is generally more economically gratifying to the end user than a new replacement, will provide an adequate return on investment. Warranty repairs due to bad core iron will be greatly reduced. For motor repair facilities and end users alike, this is a win-win situation.

"Setting the Standard in Industrial Research and Development"