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*TESTING MILITARY GRADE MAGNETICS: TRANSFORMERS, INDUCTORS and COILS**

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Engineers and designers are constantly searching for test methods to qualify or "prove-in" new designs. In the high-reliability world of military parts, design test, qualification tests, in-process tests and product characteristic tests, become even more important. The use of in-process and function tests has been adopted as a way of demonstrating that parts will operate correctly and survive their "use" environments.

This paper discusses various types of tests to qualify the magnetic components—the current-carrying capability of coils, a next-assembly "as used" test, a corona test and inductance at temperature test. Each of these tests addresses a different potential failure on a component. The entire process from design to implementation is described.

Test Classifications

A design test is used to prove-in a new design or a design change. The test method is controlled and the test setup, although documented, does not have the document control rigor of a process or function test.

An in-process test will test a component during the manufacture of the component. This is used to have control of the building processes. It will identify manufacturing problems. This test is documented and drawings are frequently controlled. It has less document control rigor than a function test.

A function test simulates the component's intended operation. In the function test, the test circuit will present the component with nearly the same inputs, loads, and environments that the component will encounter in the next assembly of the weapon system.

Presently, parts placed on the Weapon Reserve (WR) Stockpile must be operational after 30 to 40 years without use. This is why military and space applications employ very demanding component specifications to test the long-term reliability of the part. By working together with the customer, the designer determines the optimum test for potential failures such as overheating of coils or high-voltage breakdown of transformers.

All WR magnetic parts must be subjected to functional and environmental tests before they can be placed into the WR Stockpile.

Current-Carrying Capability Test

High-reliability coils in weapon systems are used in a push-pull circuit to create an ac signal from a dc source, and subsequently drive a separate secondary coil. Another common application of coils is to supply the electromotive energy to operate rotors. In both cases, a dc voltage is supplied to the coil for a specific amount of time, and then turned off for a period of time. This creates a voltage input that resembles a square pulse. This signal repeats itself for a number of cycles or time frame, as specified by the next-assembly user, each time the component is used. The coil may be tested or used in testing many times before the final assembly.

Communication between the component designer and the systems designer will establish the design specifications and the amount of testing the component will endure. This will establish the component's cycle time, rate and the total number of tests to which the component will be subjected.

In the example presented here, it was established that the coil under test will operate upwards of 2000 cycles. The dc voltage input used during operation essentially translates into a constant flow of current through the winding. This current flow creates a concern, as wire overheating can cause degradation and ultimately, premature failure.

To address this concern, a design test was created that will supply the appropriate current input and monitor the coil temperature over the time of the test. The test will supply the current to the coil at the design rate and amplitude. The test will also measure and record the applied current and the internal temperature of the coil.

Requirements:

- Apply design current (or voltage) to the coil.
- Monitor and record current applied to coil.
- Monitor and record internal temperature of coil during applied current and while current is off.
- Record time to peak temperature.
- Reapply current when internal temperature is at room temperature.
- Repeat cycle for as many times as required.

Equipment used:

- A power supply capable of delivering the required current and fast turn on (N5000 series Agilent Power Supply)
- A software-controlled switcher capable of switching the necessary current
- A voltage and resistance meter operating in a four-wire configuration (Keithley 2010)
- A current meter to measure dc current (Keithley 2010)
- A software program to control the switching time, the duration of the switcher, and record the voltage and current readings.

The three main challenges in performing this test are:

1. Determine a method to monitor the internal temperature of the coil with the required accuracy of military applications.
2. Design a system that tracks the temperature of the coil during both the “ON” and “OFF” current periods.
3. Determine an accurate way for time tracking and recording.

In order to determine the internal temperature of the coil, it was subjected to several elevated temperatures. At each temperature, the coil was soaked until the temperature was stabilized. The coil’s resistance values were recorded at each of these temperature levels. A resistance vs. temperature curve was established from these readings. This curve was directly used to figure the temperature during the OFF current time. The value of the resistance meter was compared to this curve to calculate the coil’s temperature.

During the ON time, one meter was used to measure the voltage across the coil and the other would measure the coil’s input current. These voltage and current readings were then used to calculate the resistance of the coil. Again, this resistance was compared to the curve table to find the coil temperature.

Visual Basis Software was used to address the timing issue. This software program controlled the current ON and OFF times and cycles, which usually were in the millisecond range. It also tracked the time it would take each coil to go from its peak internal temperature to ambient temperature by monitoring and recording both time and temperature in the time intervals specified by the user. A typical plot of temperature vs. time for this test can be seen in Fig. 1.

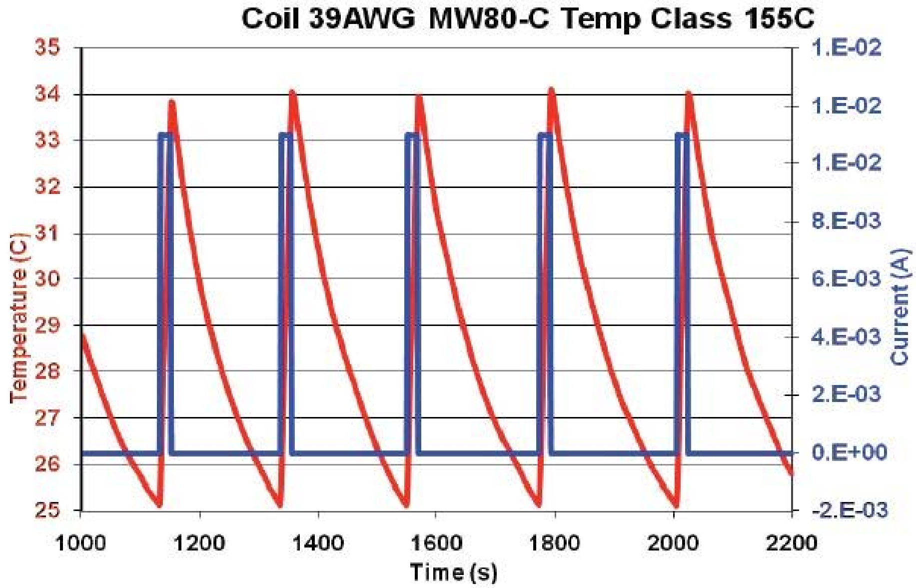

Fig.1. Temperature versus time for coil under test.

As the plot illustrates, the coil's maximum internal temperature is 34°C. This is at least 116°C below the wire maximum temperature rating of 150°C. There is no potential risk that the required testing of the part will degrade the wire.

Corona Test

Corona can be defined as a type of localized, slow and steady discharge that results from high, non-uniform electric fields. It usually streams off of a point or edge of an object in the presence of high opposing electrical charge. It causes deterioration of the insulator and can cause complete breakdown. In high-reliability transformers, a corona discharge translates into a void in the encapsulation. In high-voltage applications, this discharge creates a voltage breakdown risk, which is a potential component failure. For high-reliability transformers, 100 percent production testing is required for high-voltage transformers using the corona tester.

The corona tester is designed to determine any partial breakdowns of the device under test. Partial breakdowns have a high frequency component and occur at various voltage levels. The system shown in Fig. 2 is used to capture this frequency component, and the following methodology is used:

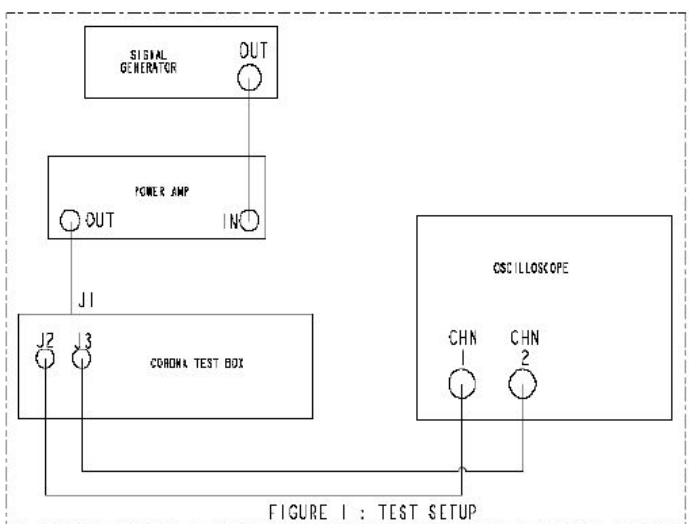

Fig 2a. Corona test setup.

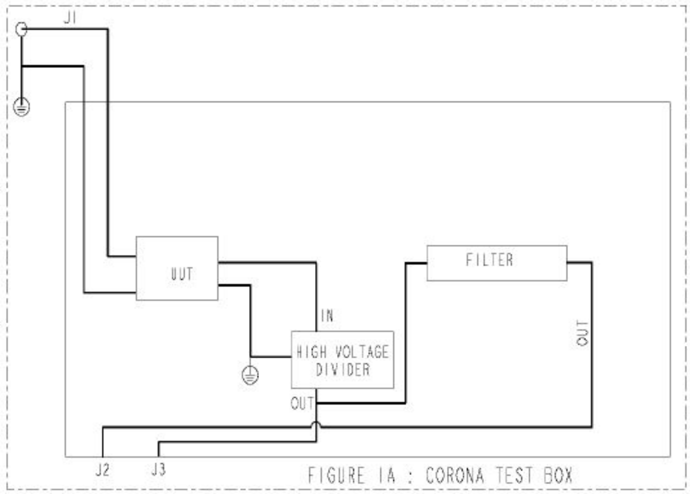

Fig 2b. Corona tester setup.

The tester input voltage—J1 in parts a and b of Fig. 2— is adjusted so that the output voltage reaches its testing voltage level (about four times its normal output). This output then goes through a 1000:1 capacitor divider that was carefully designed to minimize any loading in the high-frequency component of the corona. A 10,000-volt, 1-pF capacitor in series with a 1-nF capacitor and a resistor network were used. The divider was assembled on a PC board, set into a metal can, and filled with BIPAX Tra-Cast Epoxy. The can was tied to ground. The voltage divider's low capacitance allows all the corona high-frequency components to pass through the voltage divider along with the fundamental (operating) frequency. The output of the voltage divider is fed to the filter and to an oscilloscope, as shown in Fig. 2.

The filter is a high-pass filter and will remove the fundamental frequency. The output of the filter is fed to channel 1 of the oscilloscope – J2 in Fig. 2a. This output will have no voltage if the device under test has no corona. If corona is present, the output will show voltage pulses at various levels and at various rep-rates.

The oscilloscope is triggered on the filter output channel (channel 1). The oscilloscope's trigger mode is set to normal or single. The horizontal scale is set for one or two cycles of the fundamental frequency. Since the corona is also voltage divided, a 10-mV amplitude at the oscilloscope level represents a 10-V corona pulse. In order to trace a corona pulse slightly higher than 10 V, the trigger level is set to around 14 mV. The oscilloscope is triggered when the filter output has a corona pulse. The oscilloscope will display the corona pulse (pulses) on one channel, and the corona on the fundamental waveform on the other channel (the 1000:1 voltage-divider output). If the oscilloscope does not trigger in the allotted time, which consists of a maximum of 30 seconds, the device under test is corona-free. Fig. 3 (parts a and b) illustrate a transformer showing corona. Fig. 3 part c illustrates a corona-free transformer.

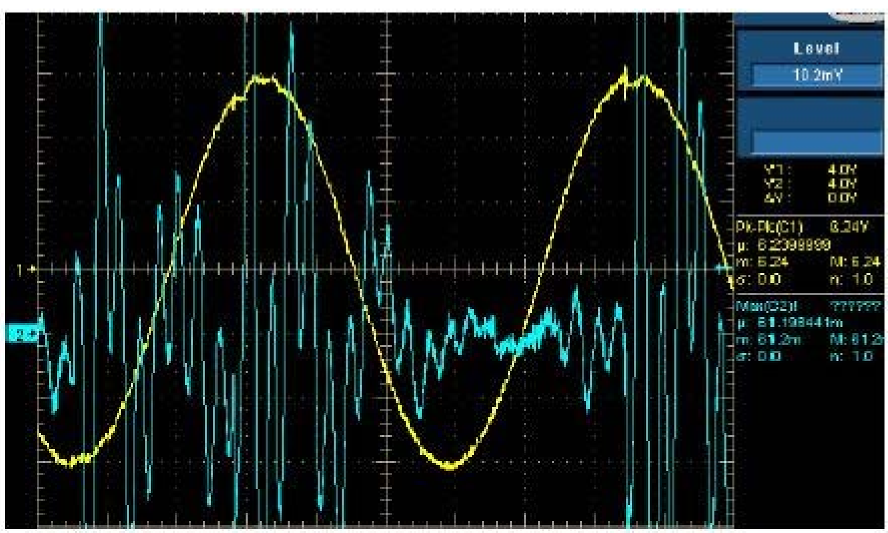

Fig. 3a. Part with Corona.

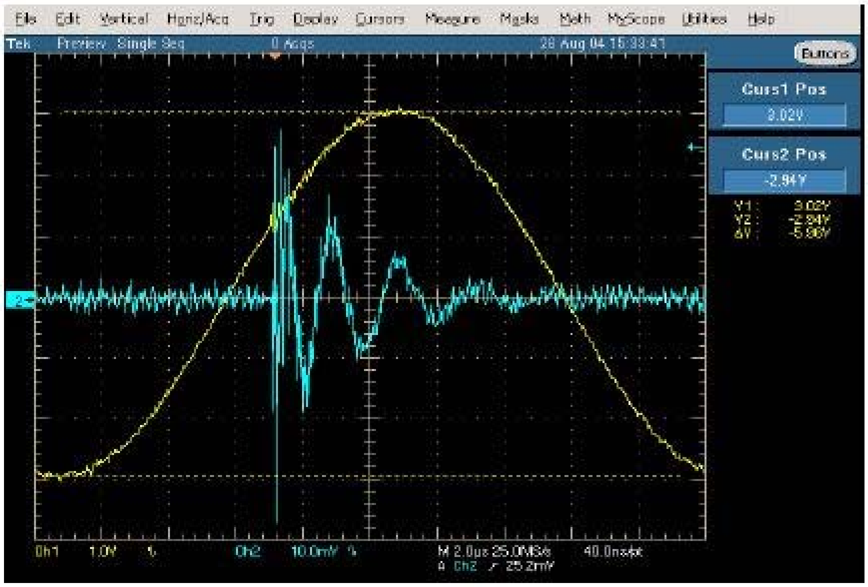

Fig. 3b. Part with Corona.

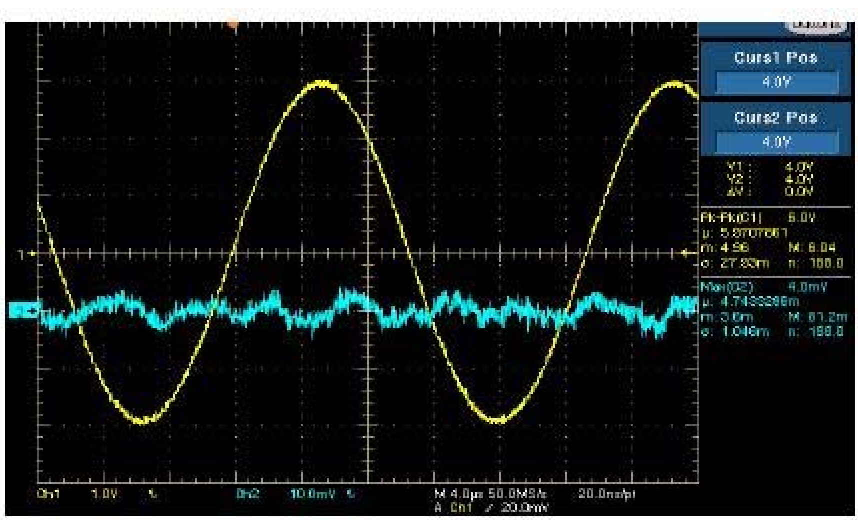

Fig. 3c. Corona-free part.

The Function Test

The component is tested with the appropriate input voltage and load per the customer specifications. This section describes the function tester of one of our high-voltage transformers.

The function tester is used to certify that the device under test (DUT) is capable of functioning as designed. This specific tester delivers the design square wave voltage of 28 V to the primary of the DUT. The output of the transformer is then fed into the design load. In this function tester, the load is a voltage quadruple consisting of a capacitor and resistive load, along with a voltage divider. The output of the voltage divider is then fed into a dc voltage meter. A schematic of the circuit is shown in Fig. 4.

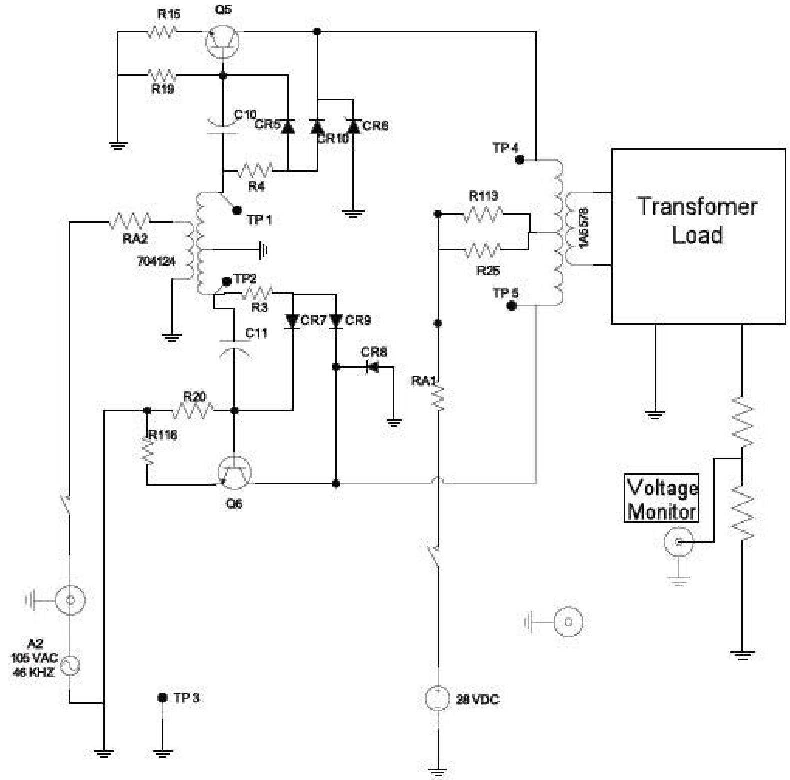

Fig. 4. Circuit schematic.

All circuitry is enclosed in a safety box with interlocks to protect the user from high voltage. The box contains a safety drop-down bar that discharges the high voltage when the lid is opened. The safety box also contains two safety interlock switches that disconnect the two voltages. These voltages supply the primary voltage to the transformer.

This tester is controlled by software. The software will control the settings on the power supply, the function generator, and the dc voltmeter. The software will read data from the dc voltmeter, close and open the contacts in the switcher, and control the timing of the test. Test results are stored in an Excel file.

Equipment

The tester's equipment consists of a safety box containing the custom electronic circuitry with a terminal block to allow the transformer to be plugged in for testing. The following equipment is also required:

- Computer-controlled switcher to switch the voltage supplies on and off
- Computer-controlled dc voltmeter to read the output voltage of the tester
- Computer-controlled dc voltage supply
- Computer-controlled function generator
- Custom-built voltage amplifier with a commercial op amp to amplify the output of the function generator and
- Check standard.

The check standard is a transformer with a known output. It is used before the start and end of each tested lot. The check standard is marked and controlled. Procedures call out the specific transformer.

Requirements

The test requirements are:

- Output charge time—the amount of time for the output to reach the design voltage.
- Steady-state voltage—the voltage output level after a specific time.

Test Sequence

Step 1. The operator connects the equipment to the tester and computer according to the drawing.

Step 2. The operator starts the tester software.

Step 3. The operator inserts the check standard and selects the check-standard test. Testing cannot begin until this test passes. The operator then removes the check standard and inserts the transformer to be tested.

Step 4. The operator selects "start test." The program closes the switcher's contacts, applying power to the transformer and starts the timers. This is time 0. At time 1, the voltmeter is read and the results are displayed. Similarly, at times 2 and 3, the voltmeter is read and the results are displayed. At time 1, the voltage has a maximum level. At time 2, the voltage has a minimum value. This will check the rise time. At time 3, the voltage has a range to be in. This will be the steady-state voltage. The results are compared to the test specifications and a pass/failed test condition is displayed.

Step 5. The program stores the test results into Excel. The test results are cleared and the tester is ready to test another part.

Inductance at Temperature Tester

Thermo stresses have a tremendous impact on the performance of a transformer, especially if it is encapsulated. The stresses can literally crack the core and tear apart a transformer. The electrical characteristics of the transformer can change so it will not perform as designed. One way of monitoring the effect of the thermo stress is to measure the inductance of the transformer while it is undergoing temperature cycling.

The concern is the changing electrical characteristics of the transformer in high- and low-temperature environments. The inductance tester described here is used to evaluate the transformer inductance under temperature extremes. This change in inductance can be caused by the ceramic core cracking or from the encapsulation applying pressure on the core and wires. This tester will monitor the inductance of the coils of the transformer and the temperature while it is subjected to temperature cycling. The inductance tester is able to monitor many components at a time, by switching relays and maintaining a calibration of the analyzer in all positions.

The transformers to be tested are mounted in a fixture board. Each fixture has a pair of relays that switch the transformer into the analyzer. The board is then placed in a temperature chamber. The chamber is programmed for the upper- and lower-temperature set points, ramp rate, and temperature soaks times. Cabling connects the board to the switcher and to the inductance analyzer. The computer's interface is connected to the analyzer and the switcher. The software program will control the switching of the relays and take and record the inductance readings.

Equipment

The inductance tester consists of the following equipment:

- Custom-made test board containing relays, temperature sensor and fixture to mount transformer
- Four BNC cables from board to analyzer
- Custom-made control cable from test board to switcher
- Switcher with 64 switches, software controlled
- Computer to run software program
- Software program
- Interface cables.

The following two graphs show the results of a high-voltage flyback transformer (Fig. 5). On both graphs, the temperature is represented by the dark blue line and the scale is on the right. The first graph (Fig. 5a) shows two transformers with no damage and the expected change in inductance. The next graph (Fig. 5b) shows three transformers with the core cracking during the changing temperature. Notice the changing inductance from the first temperature cycle and that the inductance does not recover at the start of the first cycle. Also the inductance cycles are not repeatable.

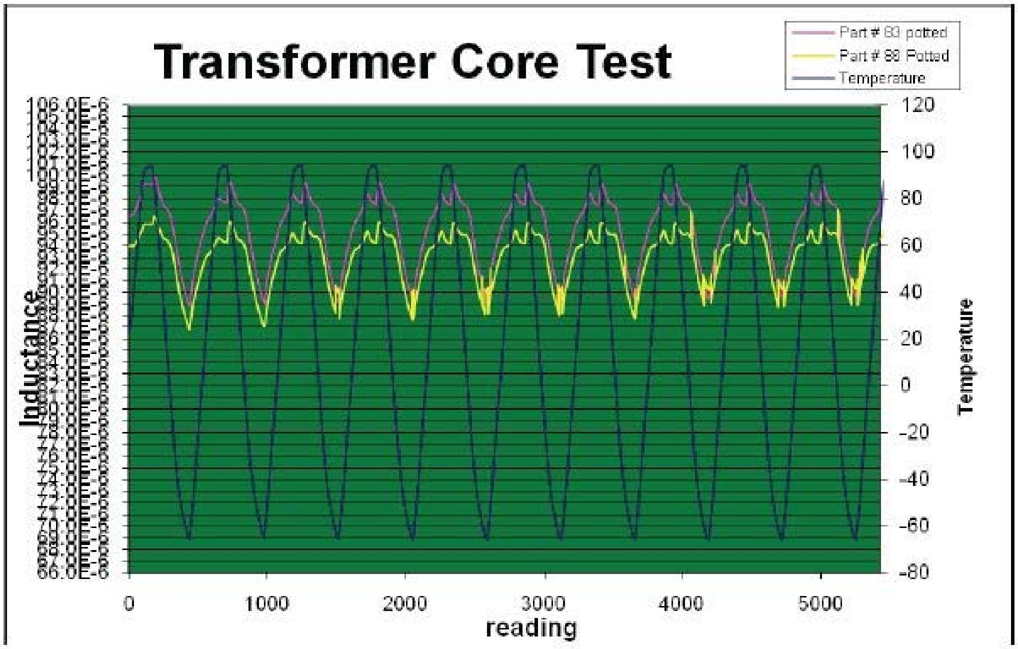

Fig. 5a. Graph of undamaged transformers.

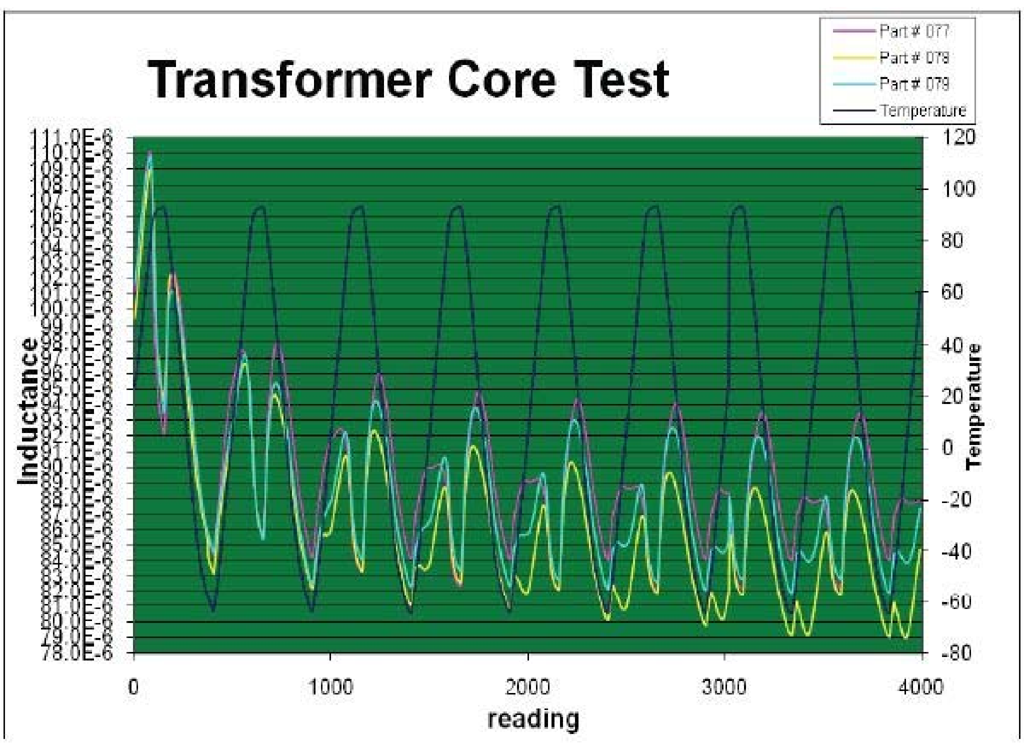

Fig. 5b. Graph of damaged transformers.

Summary

For military-grade components, it is necessary to perform these types of test to prove-in and qualify the design. This paper covered only some of the testing done on our components. Some of these tests are incorporated into the production testing of the component (i.e. corona testing). For normal production, magnetic electrical testing consisting of inductance, dc resistance, leakage inductance, turns ratio, capacitance, and insulation resistance may be completed. Function testing of the components is also required in almost all of our products.

In all of the testers, commercial equipment is used as much as possible. The equipment is assembled into a tester configuration. Calibration of equipment is a concern, so the equipment is on a scheduled calibration cycle. Software programs are developed in house. Using software increases the reliability of the test and data recording. Along with the software, custom fixturing gives reliable and repeatable testing results. Identifying critical parameters and testing these critical parameters provides a high level of confidence that the component will perform as designed in the environment for which it was designed.

References

Bou, J. and Vrabel, P. E., “Design and Implementation of Function Tests for High Rel Transformers”, Sandia National Laboratories, Albuquerque, New Mexico, 2006.

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About the Author

Paul Vrabel has worked at Sandia National Laboratories for 25 years. Most of those years were designing test circuits, fixtures and testers for various components throughout the Labs. During the past seven years, he has worked in the Magnetics Department designing, developing, and qualifying function, in-process and design testers. Paul is a member of the Product Realization Team (PRT). Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

For further reading on testing of magnetic components, see the How2Power Design Guide and search the Design Area category and select the Magnetics subcategory.