Understanding the Tests that are Recommended for Electric Motor Predictive Maintenance

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Abstract:

This paper will discuss the root causes of electrical failures in motors and how high voltage testing can help in early detection. The paper will review the insulation resistance test, polarization index test, DC hipot test, and the surge test along with outline the types of problems they can and cannot find.

Most electrical failures are caused by a combination of the voltage spikes that occur at start up and normal deterioration. The problem often begins as a turn-to-turn short that will eventually go to ground. Without high voltage testing many of these problems will go undetected.

I. Introduction

Before making a logical decision about what kinds of testing should be done on motors to predict electrical failures, it must be understood what makes these failures occur. It is important to understand the different insulation groups, the aging process of the insulation, and review typical failure scenarios. Only then can decisions be made as to which tests we should do and if high voltage testing should be included.

II. The Insulation Groups

The insulation system of a motor consists of the groundwall insulation, the phase-to-phase insulation and the turn-to-turn insulation. In a typical induction motor the groundwall insulation is the slot liner paper that protects the insulated copper to ground. The Phase-to-Phase is often a sheet of insulation paper that is laid between the phases. The weakest link in the insulation system is often the turn-to-turn insulation. This is the enamel on the copper of a random wound motor or the tape found on form coils. This insulation's purpose is to protect from copper to copper failures.

To properly test the total insulation system several different tests must be performed. The groundwall insulation can be tested with a megohmmeter to determine insulation resistance values, a polarization index test to evaluate the elasticity of the insulation, and a DC hipot to test the dielectric strength of the insulation to some predetermined level. The phase-to-phase insulation can also be tested with some of the same tests mentioned above if the motor is completely disconnected. In most predictive maintenance scenarios this will not be the case and the phase-to-phase insulation must to tested in the same manner as the turn-to-turn insulation. Surge testing is the only available test of the turn-to-turn insulation.

III. The Insulation Aging Process

The insulation aging process can be affected by one or more of these five factors:

Contamination: A chemical deposit on the windings that causes deterioration of the insulation.

Mechanical: Vibration or movement within the windings or the motor which wears the insulation system.

Normal thermal aging: The slow deterioration of the insulation over the windings natural life.

Early thermal aging: Excessive winding temperatures causing premature failure.

Overvoltage spikes: High Voltage surges caused by switching, lighting, and VFD designs.

All five of these should be considered when designing a test program. We will look at the normal thermal aging process and how it is effected by Mechanical, Early thermal aging, and the Overvoltage spikes. For this paper we will not deal with the contamination problems.

IV. What makes motors fail?

Depending on which study is referred to; electrical failures are responsible for 35% to 40%

of all motor failures. These same studies often show that many of these winding failures begin as turn-to-turn shorts caused by steep-fronted surges due to switching[2.] These studies date back to 1936. Measurements of these surges began as early as 1960 showing spikes of .5 micro-seconds at up to 5 pu.

When discussing dielectric strength and voltage spikes in this paper the measurement of "pu" will be used. One per unit (pu) is the peak line to ground voltage.

These steep-fronted surges are caused by a variety of sources. The most common and main cause of breakdown of the inter-turn insulation is switching surges.[3] These switching surges can occur both when opening and closing the contacts. Restriking will create multiple surges.

Studies show that these surges will range from 1 to 5 pu with rise times of .1 to 1 micro second. A 4160V motor will see surges of up to 17,000V.

In normal operation a typical coil will only see 10 to 100V turn-to turn. Pashens law states that a difference of 350V is required to initiate an arc. (see figure 1). With this small of a potential difference a motor should not fail due to turn-to-turn shorts from normal operation. It is the combination of weak insulation and the steep-front surges that eventually lead to motor's electrical failures.

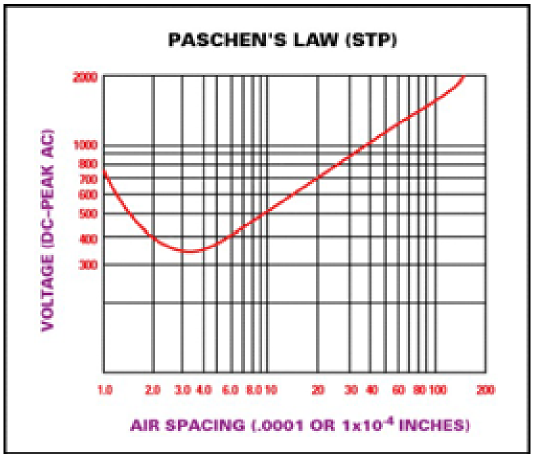

Figure 1

Mechanical abrasion within the winding is another deterioration mechanism operating on the motor's insulation. At start up a squeezing action caused by the magnetic forces will cause wear between the moving components[4]. The magnetic fields changes 120 times a second causing this squeezing to occur each time. Even though wear does exist between the winding and the ground insulation, studies show that less than 17% of the ground insulation can be worn away due to this movement. It is the turn-to turn insulation that is most affected by the abrasion.

As stated above, the potential difference turn-to-turn during normal operation is not enough to cause a failure of the turn-to-turn insulation in a motor. Only the spikes will have a voltage level high enough to cause this kind of problem. Adding to this turn-to turn stress is the non-linear distribution of voltage across the phase. In a study conducted by Christiansen and Pedersen,[5] it was concluded that the rise time of the spikes will determine how the voltage propagates over the windings. As shown in figure 2, the faster the rise time the less linear the voltage divides over the coil. As shown a typical .2 mico second rise time will drop 50% over the first coil. Other studies have shown close to 100% drop over the early turns. Large motors with form wound coils are much more likely to see this non-linearity than random wound motors.

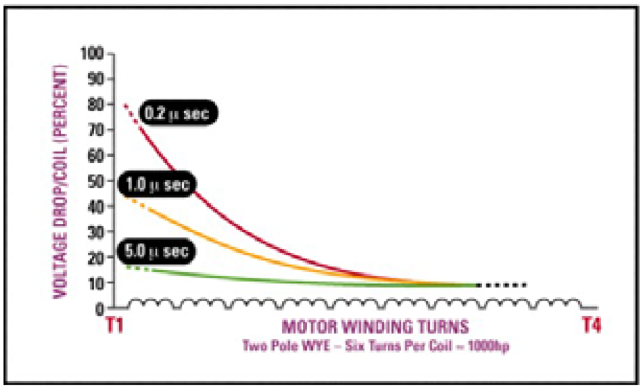

Figure 2

V. Typical Scenario of an Electrical Failure

When a motor is new the dielectric strength of the insulation system is very high. On a typical 4160V motor the strength may be over 100KV to ground with turn-to-turn strength of over 50KV. Over time the insulation will deteriorate due to the normal thermal aging process. To accelerate this process contamination and mechanical stress will cause a more rapid deterioration. This will continue until finally the insulation has deteriorated to a level that is affected by the surges. (see figure 3)

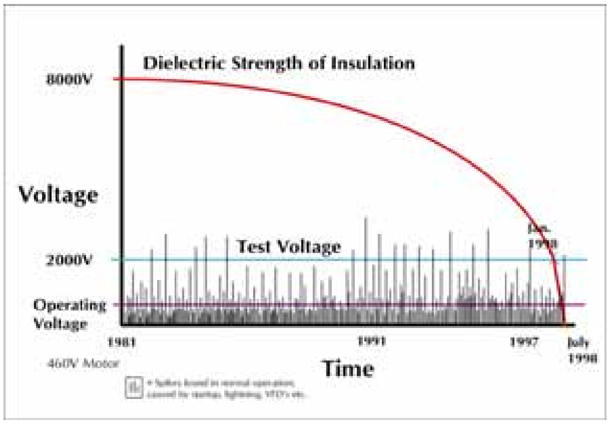

Figure 3

At this time each surge will result in an arc causing more deterioration of the insulation. When the turn-to-turn insulation erodes to a level close to the operating voltage the conductors will weld together causing rapid failure due to the high induced current. (see figure 4).

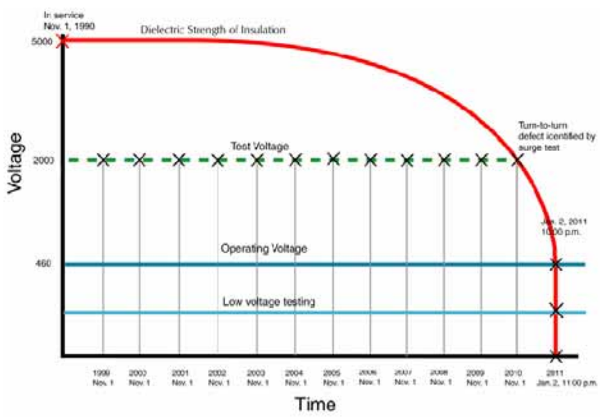

Figure 4

VI. High Voltage Testing?

Of the four tests reviewed in this paper, only two are considered to be "high voltage". It is important to understand what each of these tests can and cannot do. It is the combination of the right tests that will help meet the goal.

A. Insulation Resistance Test

Developed early in the 20th century, the insulation resistance (IR) test is the oldest and most widely used test for assessing the quality of insulation to ground. In this test, the motor frame is grounded, and the test instrument (megohmmeter) imposes a dc voltage on the motor windings. Instrument readout is provided in megohms.

A sound winding yields a readout in hundreds, or thousands, of megohms. ANSI/IEEE Std 43 *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery* prescribes as a minimum acceptable reading 1 megohm plus 1 megohm per KV of the motors rated voltage. Minimum acceptable resistance for a 460V motor, for example, is 1.46 megohms. Prudence, however, dictates that the motor be removed from service for winding refurbishment while winding-to-ground resistance is still well above the minimum acceptable value.

IR test readings are highly sensitive to temperature and moisture. For accurate, meaningful readings, testing should be done when the motor has been out of service for a long enough time for it to have reached atmospheric temperature. To preclude condensation, the temperature should be above the dew point. IR readings obtained must then be corrected to a standard temperature in accordance with tables provided by the test instrument manufacturers. This test is a test of the ground insulation only and has no value in determining the quality of the turn-to-turn insulation.

B. Polarization Index Test

This ten-minute DC test is performed at one third of the total test voltage as prescribed by IEEE Std 95. A megohm reading is taken at one minute and again at ten minutes to determine the elasticity of the ground insulation. When placed in an electric field, molecules of the ground insulation should align with that field. (see figure 5) If the insulation is aged, hard, and brittle, no polarization can occur.

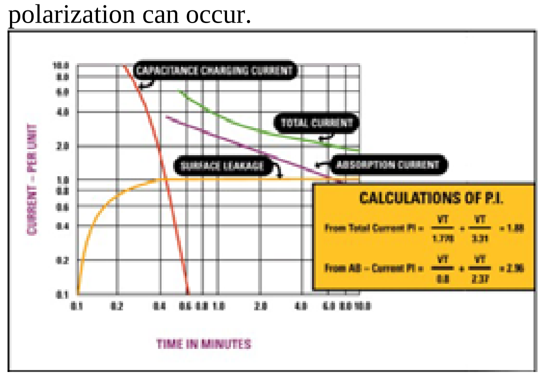

Figure 5

The Polarization index is the ratio of the ten-minute insulation resistance reading divided by the one-minute reading. Over the ten minute period this reading should increase by a factor of two or more giving a "PI" of two or more. If the insulation is very brittle the polarization index will be one or very slightly more than one, indicating no polarization took place (see figure 6). This test also looks at only the ground insulation and will not see the problems in the turn-to-turn insulation.

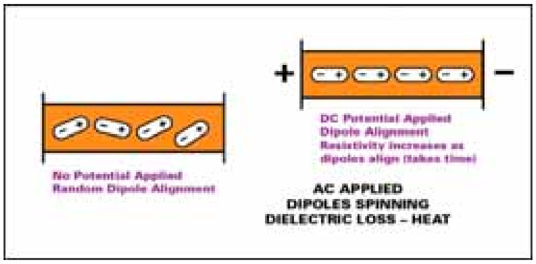

Figure 6

C. DC High-Potential (HiPot) Test

The first of the two "high voltage" tests, the DC HiPot test can uncover insulation weaknesses that might not necessarily be detected in an IR or PI procedure. In addition to measuring overall insulation resistance to ground, it provides information on insulation dielectric strength. In this sense, it can detect insulation weaknesses that are likely to fault to ground if subjected to the high transient voltage surges that commonly occur on industrial power systems.

With this test, the motor frame is grounded, and a dc voltage gradually applied in step increments up to the maximum recommended test voltage. IEEE Std 95 *Recommended Practice for Insulation Testing of Large AC Rotating Machinery With High Direct Voltage* recommends maximum test voltage at double the motor rated voltage plus 1000V. At each step up to this voltage, leakage current in microamperes in read and plotted against the corresponding dc test voltage.

The resulting plot should be a straight line. Magnitude of leakage current and resulting slope of the line is not the only consideration. The criterion of importance is that the plot be, in fact, a straight line. An abrupt upswing in the slope of the plot indicates an insulation flaw. The test should be immediately aborted to prevent the winding from failing under test. The motor can be returned to service, but winding reconditioning or replacement should be scheduled for the earliest convenient opportunity.

The number of discrete steps in which the test is performed is optional. However, taking more steps in smaller voltage increments yields better results and minimize the possibility of test voltage overshoot. Most dc high potential test sets incorporate overcurrent trips to protect the winding if a weakness is detected. The most sensitive of these overcurrent protective circuits can operate when leakage current is as low as one microamp. The DC HiPot is also a test that only looks at the ground wall and is of no value for the turn-to-turn insulation.

D. Surge Test

Although surge comparison testing was developed more than 40-years ago, it is the newest of the classic tests performed to determine winding insulation condition. This test detects turn-to-turn, coil-to-coil, and phase-to-phase insulation defects that cannot be discovered by other methods.

Surge comparison testing is premised on the principle that in a stator with no winding defects, all three-phase windings are identical. Each phase is tested against the others – A-B, B-C, and A-C. The test instrument imposes a brief voltage pulses on the phase undergoing the test and reflected ringing pulses are displayed on the instrument's oscilloscope screen. If the two windings are identical (as they should be), reflected images are identical and appear as a single trace.

This comparison method has been used in the motor shops repairing motors for over 40 years. When using a surge tester as a predictive maintenance tool, the test does not require the comparison of two wave forms. A simpler test is performed that looks for a shift to the left by the waveform of the phase being tested. This shift indicates that the dielectric strength of the turn-to-turn insulation has deteriorated to a level below that of the switching surges. Once the insulation has weakened to this point, decisions need to be made concerning the future of the motor. With today's digital technology it is possible to acquire data of the phase under test at several voltage levels and nest them together. This technique is valuable in detecting and documenting this shift to the left.

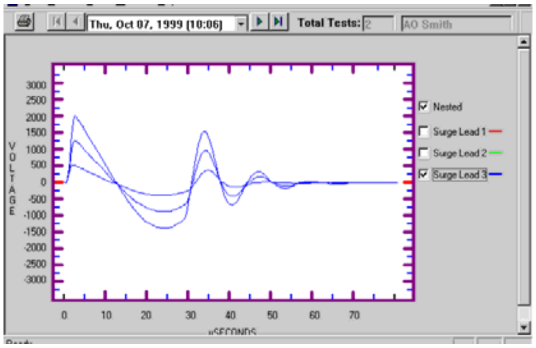

Figure 7

VII. Conclusion

When testing a motor's insulation system, it is important that the right tests are performed. Understanding that the motor sees voltages of up to 5pu, it is important that the insulation system be capable of handling stress higher than its normal operating voltage. As shown in this paper, if high voltage testing is not performed it is nearly impossible to detect the weak insulation in advance of it's failing.

Of the four tests discussed in this paper three concern themselves with the groundwall insulation with no regard for the turn-to-turn. The Surge test is the only test that looks at the turn-to-turn insulation. The turn-to-turn insulation is the root cause of a high number of the electrical failures. This test simulates characteristics of a surge at start up, making it an appropriate test for early detection of weak insulation.

References:

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