Motor Testing Theory
Static Motor Analyzers
Reference Guide
Motor Testing Theory
Static Motor Analyzer

Reference Guide

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**Megger Acquisition of Baker Instruments**

Megger Group Limited, a manufacturer of electronic test equipment and measuring instruments for power applications, acquired the Baker Instruments business from SKF Group in September of 2018.

For over 50 years, the Baker Instruments business has led the electrical motor testing industry and has a recognized leading brand and position in this area. As such, legacy products will carry the Baker Instruments or SKF brands, which will be supported by Megger moving forward.

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1  **Coil Resistance Testing Principles and Theory**

**Temperature Compensation**

The effect of temperature on both copper resistance and ground wall resistance can be substantial. Knowledge of temperature is especially important if test data is to be compared or trended to previous measurements. To compensate for temperature, enter the temperature at which the motor measurement was taken. The analyzer will correct the coil resistance tests to 25°C (per IEEE 118) and the insulation resistance/meg-ohm (IR) reading to 40°C (per IEEE 43). The effects of temperature will be discussed further in each section below as it applies to each test.

**Principles of Coil Resistance Testing**

The coil resistance test is simple to perform and is an immediate indication of the health of the conductor(s) in a winding. The coil resistance test involves an injection of a known constant current through the winding, and then measurement of the voltage drop across the winding. The coil resistance is then calculated using Ohm’s law. If a coil is shorted somewhere in the winding’s interior, the resistance will be lower than normal. You can compare the coil resistance test result to previous measurements of the same coil, measurements of identical coils, or to the motor nameplate value to identify a bad coil.

Variations of wire conductivity associated with the winding’s temperature can affect measured resistance. Measured resistance values should be corrected to reflect conductivity at a common temperature, usually 25 °C (77 °F), before comparisons are made between two measurements.

Winding can be made with both copper and aluminum. The variation of resistivity to temperature is different for each material. Therefore, the wire material must be known before compensating resistance and entered into the analyzer.

One of the difficulties encountered with measuring coil resistance is the effect of the contact resistance of clip leads used to connect to the motor’s winding. Contact resistances can be comparable or even greater than the resistance of some coils. Be sure to use four-wire (Kelvin) connections for best results.

**Indications of Problems in a Motor**

If the resistance readings are significantly different from the motor nameplate data, or if a single lead is more than a few percent different from the others, there is probably a short in one or more of the motor’s windings. If one of the values is substantially higher, there can be other problems, such as one or more of the following:

- A loose or corroded wire nut connection
- An incorrect amount of turns or incorrect wire gauge used during a rewind job
- An incorrect gauge of cable/feeder used from motor control to motor terminals
- Poor or incorrect solder technique used to connect phases
- Phases/coil groups are misconnected
2 Inductance, Impedance, and Phase Angle Measurement Principles and Theory

The windings in a motor form magnetic poles, which allow the motor to generate torque. For AC induction motors, the magnetic field from the stator windings interacts with the magnetic field of the squirrel cage rotor to generate a shaft torque. For DC motors, the interaction of the magnetic field from the stator field winding and the rotating armature winding also generates a shaft torque. Likewise, the interactions of the fields generated by the windings of a synchronous motor create shaft torque. The common agents in the different designs of these motors are windings—loops of wire that, along with a current, create a magnetic field.

Windings—loops of wire—have physical properties of inductance and resistance. Each specific coil or winding will have a characteristic inductance as well as resistance. Reason would suggest that a problem in a winding should show up as a change in inductance and resistance. Therefore, measurements of inductance and resistance are made to evaluate the winding’s overall health; more specifically, to evaluate the winding’s ability to create a magnetic field.

A brief, general review of inductance and impedance is warranted. In general, if a coil with N windings is excited with a voltage source V, there will be a current I drawn from the source.

![Coil or winding with N turns](image1)

**Figure 1. Basic coil winding schematic.**

Just how much current flows through the coil, and the phase relationship between the voltage and the current depends on the resistance of the coil’s wire, geometry of the coil, the number of coil turns, as well as the magnetic permeability of the material in the coil’s vicinity.

A graphical representation of the voltage and current is shown below:

![Representation of voltage and current over time](image2)

**Figure 2. Representation of voltage and current over time.**
Inductance, Impedance, and Phase Angle Measurement Principles and Theory

Note the phase shift between the voltage and current. The ratio of the voltage and current amplitudes along with this phase shift are used to determine the coil’s impedance.

The voltage and current are related by a “complex” impedance $Z$ defined as:

$$ Z = \frac{V}{I} $$

The impedance $Z$ will have a component in phase with the voltage (called the real part) and an out-of-phase component (called the reactive part).

$$ Z = R_{\text{real}} \ jX_{\text{reactive}} $$

The real part of the impedance not only represents the component of current in-phase with the applied voltage, it represents the part of the coil’s impedance that absorbs power. The reactive part of the impedance represents the ability of a coil to make a magnetic field. So, the motivation for measuring a coil’s impedance is clear: the ability of a coil to make a magnetic field, which is so important to the operation of a motor, is represented by the reactive component of the impedance of a coil.

Specifically, the measurement of inductance, which is proportional to the reactive impedance, is most often used when measuring a coil’s inductive or magnetic properties. The reactive impedance ($X$) and inductance of a coil ($L$) are related as follows:

$$ L = \frac{X_{\text{reactive}}}{2\pi f} $$

where $f$ is the frequency of the source. By measuring the changes in the inductance $L$, changes in the coil’s ability to make a magnetic field are determined. From a physical standpoint, the number of turns in a coil, the material properties surrounding the coil (that is, the motor core), and the shape of the coil all combine to determine the coil’s inductance. The following equation shows how these parameters combine to determine a coil’s inductance:

$$ L = A_{\text{physical\_geometry}} \ B_{\text{material\_properties}} \ N^2 $$

where the constant $A$ describes the physical shape of the coil, the constant $B$ describes the material properties of the coil’s core, and $N$ describes the number of turns in the coil. For example, a solenoid’s inductance is found to be:

$$ L = \mu_r \mu_0 N^2 \frac{A}{l} $$

where $\mu_0$ is the magnetic permeability of air, $\mu_r$ is the relative permeability of the coil’s core (approximately 1000 for electrical steels), $N$ is the number of turns, $A$ is the solenoid area, and $l$ is the solenoid length.

There are other formulas for a coil’s inductance, but the key thing to take away from these formulas is the contribution to the inductance value from the physical shape of the coil, the contribution to the inductance from materials properties, and the contribution to inductance by the number of turns (squared).
A motor’s designer carefully chooses the shape and turn count of the coil along with the core material to generate the magnetic field required to produce the desired motor shaft torque. From a maintenance point of view, changes in inductance represent changes in turn count or changes in properties of the motor’s core.

To summarize, a motor’s inductance can be used to “measure” the ability of a motor to operate. In a perfect world, an inductance measurement would be a great way to precisely perform motor diagnostics. However, the world of a real motor is not as simple as our description might lead you to believe; we’ll discuss more about the realities of inductance testing later.

**Measuring a Coil’s Inductance**

To make a coil’s inductance measurement, the voltage across the coil and the current through the coil are measured. However, just the amplitudes of the voltage and current are not sufficient to get coil inductance; the phase difference between the voltage and current is also required. Practically, a voltage amplitude measurement and the voltage phase with respect to some fixed phase reference are measured. Describing the voltage cosine of a certain amplitude and phase is shown in the following formula:

\[ V(t) = V_0 \cos(\omega t + \alpha) \]

where \( V_0 \) is the nominal voltage, \( \omega \) is the angular frequency, \( t \) is time, and \( \alpha \) is the phase angle of the voltage with respect to a reference. For notational convenience, the voltage is often written in a vector notation as:

\[ V = V_0 \angle \alpha \]

The current through the coil is described as:

\[ I(t) = I_0 \cos(\omega t + \beta) \]

where \( I_0 \) is the nominal current, \( \omega \) and \( t \) are as before for voltage, and \( \beta \) is the phase angle of the current with respect to the same reference as voltage. Again, for notational convenience, the current is written in vector notation as:

\[ I = I_0 \angle \beta \]

This kind of vector notation is expressed as “voltage at an angle alpha” or “current at an angle beta.”

The impedance of a coil is completely described by the ratio of voltage and current along with the phase relationship between the two. The impedance is written as:

\[ Z = \frac{V_0}{I_0} \angle (\alpha - \beta) \]
Inductance, Impedance, and Phase Angle Measurement Principles and Theory

Using the notation above, a proper impedance or inductance measurement will require measuring the following four items:

\[ V_0, \alpha, I_0, \beta \]

From these four parameters, the true AC impedance of a circuit is measured precisely as described in the equations above, which yields an accurate terminal inductance.

The Effect of Temperature on Inductance Measurements

Unlike DC coil resistance tests where the change of resistivity of the wire is well known, the change in inductance as temperature varies is not well known. The core material properties, which have such a strong effect on inductance measurements, are not well established in terms of how those properties change with temperature. To make the inductance measurement even more imprecise, the magnetic permeability of electrical steel also varies from one part of the lamination sheet to another part just due to the way the lamination sheet is fabricated. Therefore, there is no option to “temperature correct” inductance measurements.

Uses of the inductance measurements

Finding a Hard Turn-Turn Fault

The simplest application of inductance measurements is to determine if a winding has hard shorts. The idea is fairly simple: a serviceable winding will have a normal—or nominal—inductance related to the number of turns in the winding:

\[ L \propto N^2 \]

A winding with a short between two adjacent turns would have a decreased inductance of:

\[ L \propto (N - 1)^2 \]

For example, a stator made of form wound coils (eight turns per coil, five coils per group, and four groups per phase) has \(8 \times 5 \times 4 = 160\) turns in a phase leg. With just one turn shorted, the phase leg would have 159 turns. The percentage change in inductance would be:

\[ \Delta L = \frac{160^2 - 159^2}{160^2} \times 100 = 1.25\% \]

To identify a hard short, compare inductance readings that should be the same. For example, measure the phase to phase inductances of the three phases of an AC induction machine’s stator (without the rotor installed). If the stator is form wound, all three inductance readings will be very close to the same. If not, there is the possibility of a hard short in one of the windings.

From the example above, it is clear that the inductance measurement has to be very accurate. In practice, the inductance measurement is influenced by material properties of the core, the saturation state of the core, temperature effects, and so on. It’s tough to declare a winding bad when inductance measurements are within a few percentage points of each other. If the stator is random wound, but of the lap winding type, the inductances should be close if the winding is short free. With a short present in the random wound winding, there can be a very large change in the inductances observed because of the possibility of the first and last turns being shorted. If the stator made of concentric coils, there will be a known inductance variation because the

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concentric windings are not all exactly the same shape. Unfortunately, the spread in inductance readings due to the slightly different coil lengths make it very difficult to declare a winding to have a short or not.

To summarize, inductance values can be used to determine hard shorts in some motor windings, but not all. Knowledge of the windings is important before passing judgment on a winding’s integrity.

Example: the inductance of a GE 350HP 1750RPM 7kV stator with a short was measured at 60Hz and 1000Hz. The data is shown below:

Table 1. D3 #2 at 60Hz inductance.

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>L (%)</th>
<th>D</th>
<th>Z</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1-L2</td>
<td>168.38</td>
<td>1.30063</td>
<td>0.994</td>
<td>63.79</td>
<td>84.32</td>
</tr>
<tr>
<td>L2-L3</td>
<td>170.57</td>
<td>0.184675</td>
<td>0.075</td>
<td>64.48</td>
<td>85.7</td>
</tr>
<tr>
<td>L3-L1</td>
<td>170.255</td>
<td>1.101289</td>
<td>0.0839</td>
<td>64.41</td>
<td>85.206</td>
</tr>
</tbody>
</table>

Table 2. D3 #2 at 1000Hz inductance.

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>L (%)</th>
<th>D</th>
<th>Z</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1-L2</td>
<td>167.75</td>
<td>1.675112</td>
<td>0.0206</td>
<td>985.117</td>
<td>88.8</td>
</tr>
<tr>
<td>L2-L3</td>
<td>170.56</td>
<td>2.884615</td>
<td>0.009</td>
<td>1071.73</td>
<td>89.5</td>
</tr>
<tr>
<td>L3-L1</td>
<td>165.64</td>
<td>1.273847</td>
<td>0.0128</td>
<td>1040.86</td>
<td>89.26</td>
</tr>
</tbody>
</table>

The bar chart below shows the percentage “change” in inductance between phases of this wye-connected motor. Along with the inductance percentage values, the line-to-line error area ratio (EAR) surge test values for the same motor are also shown.

![Figure 3. Percentage “change” in inductance between wye-connected motor phases.](image)

Clearly, there is a change in inductance that is measurable for the stator with a short. The change shows up in inductance measurements at both 60Hz and 1000Hz. It is also clear from this chart that there is a much greater change in L-L EAR values of the stator with the surge test, making the surge test a much more sensitive method for finding turn shorts in windings.
Rotor Influence Check (RIC) Testing Theory

The theory of the RIC test is based in the fundamentals of an AC induction motor. AC induction motors are constructed with a stationary winding wound on the stator with a rotor containing a “squirrel cage.” The squirrel cage winding acts like a transformer secondary where a current will flow; but in this case, the secondary is allowed to rotate. The interaction of the magnetic fields caused by the squirrel cage current and the stator current creates a torque on the rotor that makes the rotor spin. The genius of this design is that the stator currents are the agent that—through the transformer effect—induces the currents in the squirrel cage.

![Squirrel cage illustration](image)

Figure 4. Squirrel cage illustration (from Wikipedia).

An AC induction motor is similar to a transformer, so a quick reminder of how a transformer works is in order. A normal transformer will behave such that the impedance of the secondary circuit will appear as impedance in the primary circuit. For example, if the secondary of a transformer is shorted, the primary will also appear to have a short. Likewise, if the secondary of the transformer is left open, the primary will also appear to be open. In general, if some resistance is placed in the secondary, a resistance will appear in the primary; but the value will be different than the actual secondary resistance value. (The primary resistance value is the ratio of the primary and secondary turns squared times the actual secondary resistance.)

\[ R_{primary} = \left( \frac{N_1}{N_2} \right)^2 R_{secondary} \]

![Basic transformer schematic](image)

Figure 5. Basic transformer schematic.

Because the squirrel cage is a transformer secondary, it stands to reason that the impedance of the squirrel cage should “transfer” to the primary (stator) of the motor. Clearly, the squirrel cage looks like a short, so a short should also “appear” in the stator circuit. But if the secondary winding (rotor) is broken, no short will appear in the primary circuit. There are several “bars” in
the squirrel cage, so if just one bar is broken, the stator impedance should look like “a little less of a short.”

Figure 6. Transformer model of a rotor in an ACIM.

This small change in stator impedance is the concept behind using stator measurements to find problems in the rotor.

In addition to broken rotor bars, RIC testing advocates claim that other issues with the rotor promoted can be identified. If the rotor is placed in the stator bore so that the rotor is not centered, there will be a difference in “transformed” impedance observed at the stator leads for each of the three phases. Also, if the rotor “wobbles” inside the stator bore, then a difference in stator impedance will also be observed.

In summary, the RIC test is reportedly able to find three rotor problems:

- Static air gap eccentricity
- Broken rotor bars
- Dynamic air gap eccentricity
To actually perform a RIC test, inductance measurements at the stator terminals are made in shaft angle increments of 5 or 10 degrees. The resulting inductance measurements are then plotted: inductance on the Y axis and shaft angle on the X axis. A typical plot is shown below:

![Figure 7. Typical RIC test curves.](image)

A plot of a motor with a broken bar is shown below. Note how the plot of inductance vs. rotor position is erratic and not as uniform as the plot above.

![Figure 8. Dayton 5hp (B2) with drilled bar: inductance measurements.](image)
There are problems with RIC testing. Namely, the test is quite unreliable and either misses rotor issues or declares there is a problem where there really isn’t one. For example, the RIC test curves shown below are from a motor with a bar drilled in several places as shown in the photo that follows the graph.

![RIC test curves](image)

**Figure 9.** Delco 3hp after running under full load. Curves do not suggest a broken rotor bar.

![Motor with drilled rotor bar](image)

**Figure 10.** Delco 3hp showing rotor bars drilled completely through.

Great care must be taken before using the RIC test to condemn a motor. The load of the motor at last shutdown, eccentricity, and steel material properties all influence the RIC test, so much so that reliable rotor bar detection is difficult.
DC Motor Armature Bar-to-bar Resistance and Impedance Test

The DC resistance and the AC impedance of adjacent bars of a DC motor’s armature can identify shorted turns within the armature winding. However, armatures are very unique windings in the sense that every bar on the commutator is in parallel with all the other bars. Because the bars are all in parallel, the DC bar-to-bar resistance will be very low: milliohms or even smaller. Likewise, the bar-to-bar inductance will be very low: microhenries or smaller.

Due to the low DC resistance and low inductance observed, a four-wire measurement is required when making bar-to-bar measurements. If a simple two-wire measurement is made, there will be severe errors in the data—with the errors of many 100s of percent possible.

The indications of a shorted coil in the armature are a drop in the DC resistance between the adjacent bars, and a drop in the inductance between the bars. An example of just such a short is provided below. Two bar charts are shown of the bar-to-bar resistance and inductance. Note how the bar-to-bar resistance goes to zero when testing the bars with the shorted coil. Also, the inductance value drops to zero. In general, the resistance/inductance vs. bar number plots will have some variation, as shown below. However, bars with shorted coils will be obvious.

![Graph of resistance and inductance done on a PC.](image)

![Example of a burned coil.](image)
DC Motor Interpole Coil Testing

Like any other winding, the resistance and inductance of interpoles (from DC motors) can be used to look for the presence of shorts in the coils. Normally, there are two, four, or six interpoles in a DC motor. The general idea is that all interpole coils should have nearly the same resistance and inductance values.

![Interpole coil](image)

**Figure 13. Interpole coil.**

**NOTICE:** Often, the interpoles are removed from the stator during a DC motor refurbishment. The interpoles are placed on a cart or work surface where they are also refurbished. When making the inductance measurement, the environment of the coil has a significant effect on the inductance value. All of the coils should be placed in the same place on a work surface that has no steel in the area. Even a brad or nail in a wooden shop bench top can change the inductance value of a coil.

The test results below show resistance and inductance data from four identical interpoles.

**Table 3. Test results from four identical interpoles.**

<table>
<thead>
<tr>
<th>Interpole</th>
<th>DC Resistance (milliohms)</th>
<th>Inductance (microhenries)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.214</td>
<td>69.2</td>
</tr>
<tr>
<td>2</td>
<td>8.214</td>
<td>88</td>
</tr>
<tr>
<td>3</td>
<td>8.218</td>
<td>77.4</td>
</tr>
<tr>
<td>4</td>
<td>8.218</td>
<td>69.3</td>
</tr>
</tbody>
</table>

The resistance measurements show that all four coils are basically the same. However, the inductance values show some variability, which suggests a problem with the coils. In this case, the variability was caused by tools located near the coils and steel support legs supporting the wooden workbench top. If proper measurements are made, a change in inductance will follow a change in the DC resistance; confirming a real short in a coil.

**NOTICE:** If the interpoles are left mounted in the stator and inductance measurements are made of each individual coil, L value differences caused by variations in the stator steel can be observed. Before condemning a particular coil, ensure that you are confident in the integrity of the measurements.
3 DC Testing Principles and Theory

High-voltage DC testing of electric motors determines the integrity of the ground wall insulation system of a motor’s winding. The ground wall insulation system consists of the wire’s insulation, slot liner insulation, wedges, and varnish.

Before going further, we need to discuss the meaning of a “HiPot test.” The label “HiPot test” describes the general idea of high-voltage testing and describes a specific type of high-voltage insulation stress test. One must differentiate between the concept of HiPot testing and the specific HiPot test based on the discussion’s context.

To perform any of the high-voltage DC tests, the red test leads from the analyzer connect to the motor’s three-phase coils and the black test lead connects to the motor’s steel core/frame. The voltage on the red test leads raises to a predetermined test voltage. The leakage current flowing from the motor’s coils through the ground wall insulation to the motor frame is measured. The analyzer then calculates the resulting insulation resistance (IR) using Ohm’s law.

Megohm Test

The megohm test applies a DC voltage to the windings of a motor after first isolating the winding from ground. Usually, you choose the test voltage to be at or near the motor’s operating voltage (see IEEE 43). You can find recommended test voltages in “Appendix B—DC and Surge Tests Voltages.”

The purpose of the megohm test is to accurately measure the insulation resistance of the ground wall insulation. The insulation resistance (IR) is a function of many variables: the physical properties of the insulating material, temperature, humidity, contaminants, and so on.

We calculate the IR value using Ohm’s law, dividing the applied voltage by the measured leakage current:

\[ IR = \frac{\text{Applied voltage}}{\text{Measured leakage current}} \]

This leakage current is the current that is actually able to pass from the winding through the ground wall insulation to the motor’s steel core plus any surface leakage currents that flow through moisture or contaminants on the insulation’s surface. To accurately determine the insulation resistance, you must reduce the surface leakage to an inconsequential level. The winding might need to be cleaned or heated to evaporate any moisture on its surface.

The insulation resistance is a function of many variables: the physical properties of the insulating material, temperature, humidity, contaminants on the surface of the winding’s insulation, and so on. We can compensate for the effects of temperature by converting the IR value to a standard temperature of 40°C (104°F), as shown later in this chapter. The effects of humidity and contaminants cannot be readily taken into account. You must use good judgment when analyzing IR values from motors that may be wet, dirty, loaded with carbon dust, and so on.

A suggested test voltage for the meg-ohm test is 1.7 times the applied/operating line voltage for the motor. For example, a 480-volt motor would be tested at 480V x 1.7 = 816VDC. You can also find recommended test voltages in IEEE 43-2000, NEMA MG-1-1993, and EASA technical manuals. Test voltages near the line-to-line operating voltages are often used. For example, 480-volt class motors would use 500 volts; 2300-volt class motors would use 2300–2500 volts; 4160-volt class motors would use 4000–5000 volts.
When first applying the voltage to a motor or when increasing the voltage, you will observe an unusually high current. This high current is not a leakage current, but the charging current of the “capacitor” formed by the motor’s copper coils, the ground wall insulation, and the motor’s steel core. We usually call this capacitor the “machine capacitance.”

**Polarization index (PI) Test Quantitatively**

The **polarization index** (PI) test quantitatively measures the ability of the ground wall insulation to polarize. The PI test is the most confusing DC test due to the subtleties involved in interpreting its results. When an insulator polarizes, the electric dipoles distributed in the insulator align themselves with an applied electric field. As the molecules polarize, a “polarization current,” (or “absorption current”) develops, adding to the insulation leakage current. The test results become confusing when attempting to attribute variations in the PI value to the polarization ability of the insulator or other affects such as humidity, moisture, and instrument error.

We typically perform the PI test at the same voltage as the megohm test. It takes 10 minutes to complete.

We calculate the PI value by dividing the IR at 10 minutes by the resistance at one minute, as shown below:

$$PI = \frac{\text{IR (10 min)}}{\text{IR (1 min)}}$$

In general, insulators that are in good condition will show a “high” polarization index, while insulators that are damaged will not. IEEE 43 recommends minimum acceptable values for the various thermal classes of motor insulation:

**Table 4. IEEE 43 Minimum acceptable values for thermal classes.**

<table>
<thead>
<tr>
<th>NEMA Class</th>
<th>Minimum Acceptable Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEMA Class A</td>
<td>1.5</td>
</tr>
<tr>
<td>NEMA Class B</td>
<td>2.0</td>
</tr>
<tr>
<td>NEMA Class F</td>
<td>2.0</td>
</tr>
<tr>
<td>NEMA Class H</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**NOTE:** Always consult any standard’s most recent edition (IEEE 43 in this case) for the latest minimum values and accepted practices.

The tester will automatically calculate the PI value at the end of a 10-minute test. At the test’s conclusion, you may store the PI value in the tester for later recall.

**Effects of Temperature**

Temperature has a strong effect on megohm readings because insulation resistance varies inversely with temperature on an exponential basis (IEEE 43 has a very good description of this effect).

Insulation resistance drops in half for every 10 °C (18 °F) rise in temperature. Therefore, before making any judgments regarding the health of a motor’s insulation based on a trend of past megohm measurements, all measurements used in the trend should be compensated or
corrected for temperature. The temperature compensation of the insulation resistance means
the user must convert all the IR measurements used in the analysis to the same temperature. The
recommended temperature to use is 40 °C (104 °F). Use the following formula to make the
calculation:

\[
R_c = \left( \frac{1}{2} \right) \times \left( \frac{40 - T}{10} \right) \times R_r
\]

For example, if an insulation resistance/megohm value is 5,000 megohms at 30 °C (85 °F), the
compensated IR value at 40 °C (104 °F) is 2,500 megohms.

Some insulating materials developed in recent years for wire insulation do not readily polarize.
For example, the newer inverter grade wire insulation does not significantly polarize. As
recommended in IEEE 43, if the one minute insulation resistance is greater than 5,000 megohms,
the PI measurement may not be meaningful. In these situations, the leakage current is often very
low – almost zero. Such low leakage currents are difficult to accurately measure and, as a result,
instrument errors become very evident. However, you must use judgment before declaring the PI
test to be meaningless. The indication of damaged insulation based on the PI test can be a very
low leakage current and a low PI value.

**Dielectric Absorption (DA) Test**

We often substitute the dielectric absorption (DA) test for the PI test for the following reasons:

- Some insulation systems do not polarize, or polarize so fast the process is not observed
- Some motors are so small that a PI test will offer no useful information
- Some motors have such a small total current leakage that it is not possible to resolve the
  polarization current
- Sometimes users do not have or do not want to take the time to perform the full
  requisite 10-minute PI test

The DA test is basically a shortened version of the PI test. Instead of forming the ratio of
insulation resistances at 10 minutes and one minute, the DA test is the IR ratio at three minutes
and 30 seconds:

\[
DA = \frac{IR(3 \text{ min})}{IR(30 \text{ s})}
\]

There are no accepted minimum or maximum values of the DA test, and the DA value often
appears to be subject to trends.

**NOTE:** Other times are used for DA testing, so you should always consult any standard’s
most recent edition (IEEE 43 in this case) for the latest values and accepted practices.

Any change in the DA value indicates that something is changing in the ground wall insulation
system. The stator may be contaminated or wet, and the stator may also be running hot and
burning insulation. Usually, changes in the DA accompany a change in one of the other
recognized tests, such as the megohm test, PI test, or the DC over-voltage test.
High Potential (HiPot) Test

The high potential (HiPot) test demonstrates that the ground wall insulation system can withstand a “high” applied voltage without exhibiting an extraordinarily high leakage current or actually breaking down. The test applies a DC voltage to the machine’s windings as in a megohm test, but at a higher voltage—usually more than twice the voltage of the motor’s operating voltage. Therefore, we often call the HiPot test a “proof” test. The insulation resistance value at the high applied voltage is not of much interest with the HiPot test. What is of interest is the value of the leakage current and, more specifically, whether the observed leakage current is within acceptable limits.

The choice of test voltage depends on whether we are testing a new motor (or coil) for acceptance, or whether we are testing an existing motor for continued service. Consult your organization’s policies regarding the HiPot test voltage to use. The simple formula of “$2V + 1,000$” generally results in a good test voltage for the HiPot test for motors already in service. You can find other recommended HiPot test voltages in IEEE 95, ANSI C50.10-1977, IEC 34.1, and NEMA MG-1 (see “Appendix D—DC and surge tests voltages”).

The HiPot test usually lasts one minute with the leakage current recorded at the end. Record the leakage current at the end of this minute for future comparisons. Between the time when the voltage is applied to the motor and the time when the leakage current measurement is taken, you should carefully observe the leakage current and watch for any variances in leakage current that may indicate weak insulation. You should consider such variations an insulation failure.
Step Voltage Test

The Step Voltage test is performed to a voltage of what the motor typically sees during starting and stopping. The test voltages are governed by IEEE and are posted below for reference.

**NOTE:** IEEE references NEMA MG 1-2006 Part 12, Page 2 and states that in no case should the test voltage be less than 1500 volts.

The DC voltage is applied to all three phases of the winding, raised slowly to a preprogrammed voltage step level, and held for a specified time period. It is then raised to the next voltage step and held for the specified time period. This is continued until the target test voltage is reached. Typical steps for a 4160-volt motor are 1000-volt increments, holding at one minute intervals. For motors less than 4160, the step voltages should be 500 volts. An example step test sequence is provided in the following illustration.

![Graph showing step voltage test example](image)

**Figure 14. Step voltage test example.**

Data is logged at the end of each step to ensure that the capacitive charge and polarization current is removed and only the real leakage current remains. This process ensures a true indication of the ground wall insulation condition.

If the leakage current (µA) rises more quickly than the voltage, insulation weakness is indicated and the test should be stopped. If the leakage current (µA) raises consistently less than the voltage rise, the motor insulation is in good standing.

The step voltage test is necessary to ensure that the ground wall insulation and cable can withstand voltage spikes encountered during normal operation.
4 Surge Testing Principles and Theory

Surge tests detect insulation damage between turns within a motor’s winding; there is no other test or way to determine if this type of insulation problem exists. A surge test applies a high-voltage high-current impulse to a winding using a fast rise time, which will induce—via Lenz’s Law—a voltage difference between adjacent loops of wire within the winding. If the insulation between the two loops of wire is damaged or somehow weakened, and if the voltage difference between the wires is high enough, it will produce an arc between the wires. You can detect the arc by observing a shift in the surge waveform.

The surge test is performed with an impulse generator and an oscilloscope type display to observe the “surge waveform” in progress. The surge waveform is a representation of the voltage present across the test leads of the analyzer during a test. The indication of a turn-to-turn fault is a shift to the left and/or a decrease in amplitude of the surge test waveform as the test voltage increases.

As mentioned above, very short high-current pulses are applied to a coil during a surge test to create a voltage gradient (or potential) across the length of the wire in the winding. This gradient produces a momentary voltage stress between turns.

The coil will respond to the surge pulse with a ringing or damped sinusoidal waveform pattern. Each coil has its own unique signature ringing or wave pattern, which can be presented on a test display screen as shown below.

![Figure 15. Ringing wave pattern resulting from surge testing.](image)

The wave pattern observed during a surge test directly relates to the coil’s inductance. (Other factors can influence the wave pattern, but inductance is the primary.) The coil becomes one of two elements in what is known as a “tank circuit,” which is an LC-type circuit made up of the coil’s inductance (L) and the surge analyzer’s internal capacitance (C).

Inductance of a coil is basically set by the number of turns in a winding and the type of iron core in which it rests. The wave pattern’s frequency is determined by the formula:

\[ Frequency = \frac{1}{2 \pi \sqrt{LC}} \]

This formula implies that when the inductance decreases, the frequency will increase.

A surge test can detect a fault between turns due to weak insulation. If the voltage potential is greater than the dielectric strength of a turn’s insulation, one or more turns may short out of the
circuit. In effect, the number of turns in the coil is reduced. Fewer working turns reduce the inductance of the coil and increase the frequency of the ringing pattern from the surge.

The voltage or amplitude of the surge wave pattern also reduces due to the decrease in inductance of a coil with a fault between turns. The following formula determines the voltage (where the current \( i \) varies according to time \( t \)):

\[
Voltage = L \frac{di}{dt}
\]

When the insulation between turns is weak, the result is a low energy arc-over and a change in inductance. When this happens, the wave pattern becomes unstable; it may shift rapidly to the left and right, and back to the original position.

A reduction in inductance occurs due to turn-to-turn faults, phase-to-phase faults, misconnections, or open connections. A surge test also performs partial ground wall testing when there is a ground line to the machine frame.

The surge test is most often used to test turn-to-turn insulation of coils or single windings. Form coils, start and run windings, and multi-tapped windings are a few examples. Surge tests are also used to compare new windings to a standard winding to assure they conform.

**Surge Test Display**

A complete surge test screen is provided below for reference.

![Figure 16. Example surge test result.](image)

For each direction a coil is tested, check the display for the wave pattern produced in each test. If there are two good stable patterns, the winding is good. If you see anything other than good patterns, there is a possible fault. Refer to the “Determining a fault” section below for explanations of wave patterns indicating good or faulty windings. Keep in mind that fault determination is often a result of experience.

**Example: Comparison to a Master Coil**

Occasionally a manufacturer may want to test against a standard. In such a situation, a selected standard coil is surge tested, results are stored in memory, and then they are recalled to the screen. All unknown coils would be tested and compared to the standard coil’s wave pattern. Standard testing demonstrates the coil’s ability to withstand minimum test voltages and you can compare the signature waveform to the standard’s single waveform.
**Determining a Fault**

If a fault exists in a motor, the wave pattern on the display will collapse in amplitude and a distinct shift to the left will occur, signifying an increase in frequency (a decrease in inductance). When inductance decreases, the frequency of the wave pattern will increase according to the formula above. The figure below illustrates this. This type of fault is generally one that indicates a failure of the turn-to-turn short.

![Figure 17. Good coil waveform (left) vs. bad (right).](image)

If any wave pattern becomes erratic and/or flickers during testing, intermittent shorting or arcing is probably occurring in the windings under the voltage stress. Audible sounds often accompany arcing. It may be desirable to store the wave pattern by this arcing for reference if you can release the test or freeze the wave pattern at the moment when the wave pattern appears most affected by the fault (for example, reduced amplitude and increased frequency or shift to the left).

**NOTE:** If all three wave pattern comparisons in surge testing show considerable separation when testing three-phase windings, the motor has a phase-to-phase short.
Motivation for Surge Testing

Motors are subjected to high-energy, high-voltage transients in everyday operating environments. These transient pulses can damage the insulation in the motor and—given enough time—cause a catastrophic failure with the motor. High-energy, high-voltage transients are typically caused by:

- Motor start-up current coupled with contact bounce in the MCC
- Lightning strikes in the power system
- Inverter drive transients
- Line surges caused by tripped motors or transformers elsewhere in the power system

One of the primary functions of a tester is to simulate real-world transient voltages likely to be encountered by the motor without the high energy typical of real-world transients. Such spikes are a significant aging factor for the end turn insulation of an electric motor.

Contact Bounce

Odds even, one of the major sources for the high-energy transients is the MCC, a device that is supposed to protect the motor. When the breaker contacts close in the MCC during startup, they will often “bounce” or chatter; this means that the high inrush current is being made and breaking several times. As a result of interrupting the current, an inductive “kick back” voltage spike develops. Large inrush currents along with the high inductance of electric motors are what give these “kick back” voltage spikes their high energy.

Lightning Strikes

Lightning strikes often hit power systems or grids. Although a great amount of effort is made to protect grids from lightning damage, high-voltage transients caused by strikes can still reach motors.

Inverter Transients

Variable speed drives or pulse width modulated drives are based on switching currents very quickly in such a manner that the motor runs at a preset speed. The switching of the current, combined with the obvious fact that the motor is an inductor, results in the motor drive electronics generating high-speed transients. These transients impress on the motor where they can slowly degrade the insulation in the motor windings.

Line Surges

The stored energy in a motor or transformer must dissipate when that motor or transformer trips offline from its power system. Either the device absorbs the energy or the energy pushes out onto the power system where other transformers or motors absorb the energy. Often, large transient voltage spikes are generated when this energy is released on a power system. Such spikes can easily damage motors, especially if the motor has weakened insulation.
Partial Discharge Detection

Partial Discharge (PD) is a well-known phenomenon in the operation of motors as a predictive feature of insulation condition monitoring. PD is a localized, partial bridging between conductors due to dielectric breakdown caused by high-voltage stress that does not fully short the two conductors. These discharges, when severe enough, can create a persistent visible glow known as corona, while less severe breakdowns can cause smaller invisible partial discharges. These smaller discharges are of concern in high-voltage motors and low-voltage motors being driven by variable frequency inverters due to start-up transients and the tendency of these inverters to create large over voltages during switching that stress the insulation between coil windings.

PD Causes

PD can occur in multiple locations such as gas-filled voids within the insulation, on the surface of the insulation due to contamination or tracking, and between the ground wall and the coil windings. Voids can be caused by improper impregnation of the coil insulation, surface contamination, or can occur over time as persistent high-voltage stresses break down the insulating material.

Due to the high-voltage differentials occurring across these areas, the gas/material can ionize and arc, further stressing the insulation and causing greater damage; the ultimate result is complete coil bridging, leading to motor failure. Discharges between the ground wall and the coil windings can occur due to poor coil lamination or an external cause such as contamination that weakens the dielectric properties between the coil and ground wall.

PD Detection

When PD occurs in a coil, the discharged electric potential radiates high-frequency EM waves both into the atmosphere and on the reflected voltage waveform in the surge detector. These waves can then be received and extracted from the primary voltage waveform to deduce the presence of discharges along the windings. Many methods for receiving this information exist, including RF, acoustic, high-frequency current transformers (HFCTs), and voltage division and filtering.

A PD event is a detected voltage level that exceeds a specified voltage level (PD event threshold, defined in mV). When PD events detected exceed a specified number of events, a PD pulse is said to occur.

PD detection schemes rely on IEC-61934 to provide standards for the detection and communication of partial discharge severity. The schemes use four key measurements:

- Partial Discharge Inception Voltage (PDIV)
- Repetitive Partial Discharge Inception Voltage (RPDIV)
- Repetitive Partial Discharge Extinction Voltage (RPDEV)
- Partial Discharge Extinction Voltage (PDEV)

Other metrics that provide useful information on the intensity and severity of the discharges include the number of events or discharges per surge pulse, and the amplitude of the discharges occurring.
Surge Testing Principles and Theory

PD Terminology

**PD signal**—a signal rising out of the high frequency information extracted from the surge waveform.

**PD event**—when a PD signal crosses the voltage threshold (PD threshold set in User Settings screen; defined in mV).

**PD pulse**—when PD events detected exceeds number of events value (PD # events set in User Settings screen).

Summarized PD Detection Process

The software counts the number of PD events within each surge pulse. When PD events detected exceeds the number of events value, a PD pulse is said to occur.

The first time the software detects a PD pulse is when the software records the current surge voltage level as PDIV.

At the point where more than 50% of the surge pulses have a PD pulse, the software records the current surge voltage level as RPDIV.

At the point where less than 50% of the surge pulses have a PD pulse, the software records the current surge voltage level as RPDEV.

As the voltage continues to ramp down, the software continually records the current surge voltage level at which a PD pulse is detected. The last recorded value is “saved” as the PDEV (the lowest voltage at which the detector sees a PD pulse).

PD is typically seen within the first peak of the surge pulse, but may also be seen within the second peak if the PD events exceed the PDIV value.
Appendix A — Applicable Standards

Applicable Standards
- EASA Standard AR100-1998 Recommended Practice for the Repair of Rotating Electrical Apparatus
- IEEE 43-2000 Recommended Practice for Testing Insulation Resistance of Rotating Machinery
- IEEE 112-1991 Test Procedures for Polyphase Induction Motors and Generators
- IEEE 113-1985 Guide on Test Procedures for DC Machines
- IEEE 115-1983 Test Procedures for Synchronous Machines
- IEEE 429-1972 Evaluation of Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Stator Coils
- IEEE 432-1992 Guide for Insulation Maintenance for Rotating Electrical Machinery (5 hp to less than 10,000 hp)
- IEC 61934 for PD and IEEE 927 (for PD)

Referenced EMC Standards
- EMC Directive 2004/108/EC
- IEC 61000-6-2, Second Edition: 2005
- IEC 61000-6-4, Second Edition: 2006
- CISPR 11:2004
- EN 61000-3-2:2006
- EN 61000-3-3:2005

Referenced Safety Standards
- EN 61010-1:2001 Second Edition
Applicable standards

Reprints or EASA standards are available from:
1331 Baur Boulevard
St. Louis, MO 63132
Phone: 314-993-2220
FAX: 314-993-1269
www.easa.com

Reprints of IEC standards are available from:
International Electrotechnical Commission (IEC)
www.iec.ch

Reprints of IEEE standards are available from:
IEEE Customer Service
445 Hoes Lane
Piscataway, NJ 08855-1331
Phone: 1-800-678-IEEE
Fax: 908-981-9667
www.ieee.org

Reprints of NEMA standards are available from:
National Electrical Manufacturers Association (NEMA)
Global Engineering Documents
Phone: 1-800-854-7179
International: 303-379-2740
Appendix B — DC and Surge Tests Voltages

Recommended Test Voltages

SKF has a recommended standard (see table) for test voltages for DC tests and surge tests conducted on a motor, generator, or transformer. That standard is twice the AC line voltage plus 1,000 volts.

This test voltage is consistent with NEMA MG-1, IEEE 95-1977 (for test voltage greater than 5,000 volts) and IEEE 43-2000 (test voltages less than 5,000 volts).

View other standards in the tables below for a comparison of IEEE 95, EASA DC-HiPot, IEEE 522 surge testing, IEC 34-15, and SKF recommended testing voltages.

NOTE: The tables list representations of motors, as well as the formulas to calculate voltages so that you can calculate test voltage of any size motor.

Table 5. Motor representations and formulas for calculating voltages.

<table>
<thead>
<tr>
<th>V Line</th>
<th>Per Unit</th>
<th>Min Test, V Line × 1.25 × 1.7</th>
<th>Max Test, V Line × 1.5 × 1.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>480</td>
<td>392</td>
<td>1,020</td>
<td>1,224</td>
</tr>
<tr>
<td>575</td>
<td>469</td>
<td>1,222</td>
<td>1,466</td>
</tr>
<tr>
<td>600</td>
<td>490</td>
<td>1,275</td>
<td>1,530</td>
</tr>
<tr>
<td>2,300</td>
<td>1,878</td>
<td>4,888</td>
<td>5,865</td>
</tr>
<tr>
<td>4,160</td>
<td>3,397</td>
<td>8,840</td>
<td>10,608</td>
</tr>
<tr>
<td>6,900</td>
<td>5,634</td>
<td>14,663</td>
<td>17,595</td>
</tr>
<tr>
<td>13,800</td>
<td>11,268</td>
<td>29,325</td>
<td>35,190</td>
</tr>
</tbody>
</table>

Table 6. SKF recommended standards

<table>
<thead>
<tr>
<th>V Line</th>
<th>Per Unit</th>
<th>In Service, 2E + 1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>480</td>
<td>392</td>
<td>1,960</td>
</tr>
<tr>
<td>575</td>
<td>469</td>
<td>2,150</td>
</tr>
<tr>
<td>600</td>
<td>490</td>
<td>2,200</td>
</tr>
<tr>
<td>2,300</td>
<td>1,878</td>
<td>5,600</td>
</tr>
<tr>
<td>4,160</td>
<td>3,397</td>
<td>9,320</td>
</tr>
<tr>
<td>6,900</td>
<td>5,634</td>
<td>14,800</td>
</tr>
<tr>
<td>13,800</td>
<td>11,268</td>
<td>28,600</td>
</tr>
</tbody>
</table>

NOTE: Use the “Peak Voltage” value shown on the screen to obtain the proper test voltages.
## DC and Surge Tests Voltages

### IEEE 95-1977

**Table 7. EASA DC-Hipot.**

<table>
<thead>
<tr>
<th>V Line</th>
<th>Per Unit</th>
<th>New, $3.4 \times V$ Line + 1,700</th>
<th>In Service, 65% of New</th>
</tr>
</thead>
<tbody>
<tr>
<td>480</td>
<td>392</td>
<td>3,332</td>
<td>2,165.8</td>
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<td>575</td>
<td>469</td>
<td>3,655</td>
<td>2,375.75</td>
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<td>600</td>
<td>490</td>
<td>3,740</td>
<td>2,431</td>
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<td>2,300</td>
<td>1,878</td>
<td>9,520</td>
<td>6,188</td>
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<td>4,160</td>
<td>3,397</td>
<td>15,844</td>
<td>10,298.6</td>
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<td>6,900</td>
<td>5,634</td>
<td>25,160</td>
<td>16,354</td>
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<tr>
<td>13,800</td>
<td>11,268</td>
<td>48,620</td>
<td>31,603</td>
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</tbody>
</table>

**Table 8. IEEE 522 surge testing.**

<table>
<thead>
<tr>
<th>V Line</th>
<th>Per Unit</th>
<th>New, $3.5 \times$ Per Unit</th>
<th>In Service, 75% of New</th>
</tr>
</thead>
<tbody>
<tr>
<td>480</td>
<td>392</td>
<td>1,372</td>
<td>1,029</td>
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<td>575</td>
<td>469</td>
<td>1,642</td>
<td>1,232</td>
</tr>
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<td>600</td>
<td>490</td>
<td>1,715</td>
<td>1,286</td>
</tr>
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<td>2,300</td>
<td>1,878</td>
<td>6,573</td>
<td>4,930</td>
</tr>
<tr>
<td>4,160</td>
<td>3,397</td>
<td>11,890</td>
<td>8,917</td>
</tr>
<tr>
<td>6,900</td>
<td>5,634</td>
<td>19,719</td>
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<tr>
<td>13,800</td>
<td>11,268</td>
<td>39,438</td>
<td>29,578</td>
</tr>
</tbody>
</table>

**Table 9. IEC 34-15.**

<table>
<thead>
<tr>
<th>V Line</th>
<th>Per Unit</th>
<th>$V$ Line $\times 4E + 5,000$</th>
<th>0.2 us, 65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>480</td>
<td>392</td>
<td>6,920</td>
<td>4,498</td>
</tr>
<tr>
<td>575</td>
<td>469</td>
<td>7,300</td>
<td>4,745</td>
</tr>
<tr>
<td>600</td>
<td>490</td>
<td>7,400</td>
<td>4,810</td>
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<td>2,300</td>
<td>1,878</td>
<td>14,200</td>
<td>9,230</td>
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<td>6,900</td>
<td>5,634</td>
<td>32,600</td>
<td>21,190</td>
</tr>
<tr>
<td>13,800</td>
<td>11,268</td>
<td>60,200</td>
<td>39,130</td>
</tr>
</tbody>
</table>
Appendix C — Typical Winding Faults

This chapter is designed to assist with interpreting test results. Although it is not a substitute for experience gained in the field, it might assist those new to motor testing by providing examples. It will also explain each of the failure messages the software generates when a failure is detected.

Due to the wide range of motors and their test parameters, always refer to the motor manufacturer and published standards for appropriate voltage levels and acceptance limits.

Basic Wave Patterns Used to Determine Faults

There are several basic wave patterns (for assembled motors, refer to “Rotor Loading”):

1. Good stable trace—indicating turn-to-turn and phase-to-phase insulation integrity.
2. Instability and separation—indicating a fault or weakness in winding or phase insulation.
3. Open circuit—indicating an open phase or disconnected test leads.
4. Grounded phase.
5. Separated waveforms—indicating a solid turn-to-turn or phase-to-phase short (if the rotor is not in place).

The motor windings are considered good if all three lead’s wave patterns are the same and remain stable up to the specified test voltage.

For initial determination of winding faults, refer to the following wave pattern examples. These are typical wave patterns seen for three-phase, lap-wound induction stators. They provide a reference for identifying a characteristic wave pattern with a type of fault.

**NOTE:** Variation from these wave patterns is to be expected. Do not consider these wave patterns to be absolute. Due to the variety of motor windings and connections that exist, each winding will have its own signature wave pattern.
Typical Winding Faults

Good Stable Trace

![Good Stable Trace](image)

Figure 18. Good stable trace.

Arcing Turn-to-turn Short

![Arcing Turn-to-turn Short](image)

Figure 19. Arcing turn-to-turn short.

In this waveform, the solid line represents an unstable, intermittent shorting in the windings. Notice its shift to the left of the dotted line.
Open Circuit
When an open condition exists in the tested phase, a pattern resembling a ski ramp is seen. This is due to a loss of continuity throughout the tested winding. If only one phase is open, normal waveforms will appear for the other phases. This pattern is also seen when nothing is connected to the Surge test leads.

![Open Circuit Diagram](image)

**Figure 20. Open circuit.**

Hard Short to Ground
If a hard short to ground exists, the Meg-ohm or HiPot test will detect it. It can also be detected when surge testing. The wave pattern will appear as a relatively flat line. The example below illustrates a grounded phase.

![Hard Short to Ground Diagram](image)

**Figure 21. Hard short to ground.**
Solid Turn-to-turn Short (fused or welded short)

![Graph showing solid turn-to-turn short](image)

**Figure 22. Solid turn-to-turn short.**

The waveform above indicates a short in a motor without a rotor in place.

**Application Notes**

- Knowledge of all types of wave patterns is not necessary when maintenance testing. It is more important to look for a stable, uniform waveform up to the specified test voltage.
- Test leads should be checked for breakage by firmly grasping the boot and clip in one hand while pulling on the lead with the other. A broken lead will stretch and a good lead will not.
- When an open circuit is indicated, check the connections between all three test leads and the winding being tested.
- Also check for open test leads at the clip end. Test leads should be checked weekly to ensure there is no breakage.
- Baseline testing can be conducted to determine appropriate DC test pass/fail tolerances. Maintenance testing should be performed using procedures that are kept consistent from test to test.
- Depending on the severity, motors that fail tests should be considered for service or replacement.

**Factors that Affect Analyzer Output**

Sometimes, full output of the analyzer can be below its rated maximum output voltage. This occurs on low-impedance devices or devices that exceed the analyzer’s capability.

For example, the horsepower of a motor might be too high. In this case, a 12,000-volt analyzer might only apply 4000 volts when the output is set halfway between minimum and maximum. At this mid-point, 6000 volts is expected. The analyzer might then give only a maximum output of 7000 volts when 12,000 volts is expected.

The test should be considered successful if the desired test voltage level can be reached. For the example above, if the motor was 3000 horsepower and operated at 2300 volts, an appropriate test voltage would be $2 \times 2300V + 1000V = 5600V$. The size of the motor can limit the analyzer’s output to a level below its rating.
Adjacent windings—such as a start winding, part winding, high-voltage, or low-voltage winding—should be jumpered together (and in many cases grounded) while doing the test. This procedure can eliminate incorrect test results caused by inductive coupling.

**Table 10. Common testing issues and effects.**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor larger than recommended max size to test.</td>
<td>Capacitance and inductance of motor windings can load down the analyzer output. The voltage output is reduced below maximum output, which can damage the analyzer if the test is applied for an extended period. Note: The test is considered successful if the test voltage 2E + 1000V is achieved.</td>
</tr>
<tr>
<td>Motor rated RPM is slow.</td>
<td>For each reduction of the motor’s RPM, (that is, 3600 -&gt; 1800) the effective horsepower of the motor that the analyzer senses is doubled. Example: A 500 hp/3600 RPM motor = 500 hp. A 500 hp/1800 RPM motor = 1000 hp. A 500 hp/900 RPM motor = 2000 hp, and so on.</td>
</tr>
<tr>
<td>Motor has high number of poles.</td>
<td>Same condition as comment above on motor RPM.</td>
</tr>
<tr>
<td>Feeder cable length.</td>
<td>Distributed capacitance of the feeder cable loads down the test according to the formula: $V_{\text{max capable}} = \frac{V_{\text{tester}} \times \text{tester cap}}{\text{Tester cap} + \text{Cable cap}}$ The analyzer may be unable to generate the desired test voltage. It is observed that the closer the motor is to the recommended maximum motor size to test, the shorter the feeder cables must be. If the motor is very small compared to the maximum recommended motor to test, the analyzer may have sufficient energy such that longer feeder cables, as well as the motor windings, can be tested.</td>
</tr>
<tr>
<td>Shielded feeder cable.</td>
<td>The above condition becomes extreme. Shielded feeder cables have very high capacitance.</td>
</tr>
<tr>
<td>High horsepower motors at low operating voltage.</td>
<td>The characteristics of these motors are such that the winding impedance is low, requiring high analyzer output energy to surge test the windings. If the analyzer output is insufficient to test a motor, then a power pack option might be necessary. Or, if testing at the motor or the MCC, very short feeder cables lengths will be needed.</td>
</tr>
<tr>
<td>Motor assembled with rotor in place.</td>
<td>The presence of the rotor will load the analyzer by drawing energy from the analyzer like the secondary of a transformer.</td>
</tr>
</tbody>
</table>
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