Learn how to identify winding insulation breakdown and bearing wear to prevent motor failure and improve asset uptime.

BY HILTON HAMMOND

Images courtesy of Fluke Corp.

Motors are used everywhere in industrial environments and they are becoming increasingly complex and technical, sometimes making it a challenge to keep them running at peak performance. It is important to remember that the causes of motor and drive issues are not confined to a single domain of expertise—both mechanical and electrical issues can lead to motor failure—and being armed with the right knowledge can mean the difference between costly downtime and improved asset uptime.

Winding insulation breakdown and bearing wear are the two most common causes of motor failure, but those conditions arise for many different reasons. This article demonstrates how to detect the 13 most common causes of motor drive system failures.

Power quality

1. Transient voltage—Transient voltages (see Figure 1) can come from a number of sources either inside or outside of the plant. Adjacent loads turning on or off, power factor correction capacitor banks or even distant weather can generate transient voltages on distribution systems. These transients, which vary in amplitude and frequency, can erode or cause insulation breakdown in motor windings. Finding the source of these transients can be difficult because of the infrequency of the occurrences and the fact that the symptoms can present themselves in different ways. For example, a transient may appear on control cables that do not necessarily cause equipment damage directly, but may disrupt operations. Impact: Motor winding insulation breakdown leads to early motor failure and unplanned downtime

Instrument to measure and diagnose: Three-phase power quality analyzer

Criticality: High

2. Voltage imbalance—Three-phase distribution systems often serve single-phase loads. An unbalance in impedance or load distribution can contribute to unbalance across all three of the phases. Potential faults may be in the cabling to the motor, the terminations at the motor and potentially the windings themselves (see Figure 2). This imbalance can lead to stresses in each of the phase circuits in a three-phase power system. At the simplest level, all three phases of voltage should always have the same magnitude. Impact: Imbalance creates excessive current flow in one or more phases that then increases operating temperatures, leading to insulation breakdown

Instrument to measure and diagnose: Three-phase power quality analyzer

Criticality: Medium

3. Harmonic distortion—Simply stated, harmonics are any unwanted additional source of high-frequency ac voltages or currents supplying energy to the motor windings. This additional energy is not used to turn the motor shaft but circulates in the windings and ultimately contributes to internal energy losses. These losses dissipate in the form of heat that, over time, will deteriorate the insulation capability of the windings. Some harmonic distortion of the current is normal on any part of the system serving electronic loads. To start investigating harmonic distortion, use a power quality analyzer to monitor electrical current levels
With the right knowledge, prioritization and preventive maintenance efforts, equipment failures related to normal operating stresses can be avoided.

and temperatures at transformers to be sure that they are not overstressed. Each harmonic has a different acceptable level of distortion, which is defined by standards such as IEEE 519-1992.

**Impact:** Decrease in motor efficiency results in added cost and an increase in operating temperatures

**Instrument to measure and diagnose:** Three-phase power quality analyzer

**Criticality:** Medium

### Variable-frequency drives

#### 4. Reflections on drive output PWM signals—Variable-frequency drives employ a pulse width modulation (PWM) technique to control the output voltage and frequency to a motor (see Figure 4). Reflections are generated when there is an impedance mismatch between the source and load. Impedance mismatches can occur as a result of improper installation, improper component selection or equipment degradation over time. In a motor drive circuit, the peak of the reflection could be as high as the dc bus voltage level.

**Impact:** Motor winding insulation breakdown leads to unplanned downtime

**Instrument to measure and diagnose:** Fast-sampling four-channel portable oscilloscope

**Criticality:** High

#### 5. Sigma current—Sigma currents are essentially stray currents that circulate in a system (see Figure 5). The sigma currents are created as a result of the signal frequency, voltage level, capacitance and inductance in conductors. These circulating currents can find their way through protective earth systems causing nuisance tripping or, in some cases, excess heat in windings. A sigma current can be found in the motor cabling and is the sum of the current of the three phases at any one point in time. In a perfect situation, the sum of the three currents would equal zero. In other words, the return current from the drive would be equal to the current to the drive. Sigma currents can also be understood as asymmetrical signals in multiple conductors that can capacitively couple currents into the ground conductor.

**Impact:** Mysterious circuit trip due to protective earth current flow

**Instrument to measure and diagnose:** Isolated four-channel portable oscilloscope with wide bandwidth (10 kHz) current clamp

**Criticality:** Low
6. Operational overloads—Motor overload occurs when a motor is under excessive load (see Figure 6). The primary symptoms that accompany a motor overload are excessive current draw, insufficient torque and overheating. Excessive motor heat is a major cause of motor failure. In the case of an overloaded motor, individual motor components (including bearings, motor windings and other components) may be working fine, but the motor will continue to run hot. For this reason, it makes sense to begin troubleshooting by checking for motor overload. Because 30% of motor failures are caused by overloading, it is important to understand how to measure for and identify motor overloading.

Impact: Premature wear on motor electrical and mechanical components leading to permanent failure
Instrument to measure and diagnose: Digital multimeter
Criticality: High

7. Misalignment—Misalignment occurs when the motor drive shaft is not in correct alignment with the load, or the component that couples the motor to the load is misaligned (see Figure 7). Many professionals believe that a flexible coupling eliminates and compensates for misalignment, but a flexible coupling only protects the coupling from misalignment. Even with a flexible coupling, a misaligned shaft will transmit damaging cyclical forces along the shaft and into the motor, leading to excess wear on the motor and increasing the apparent mechanical load. In addition, misalignment may feed vibration into both the load and the motor drive shaft. There are a few types of misalignment:

- Angular misalignment where the shaft centerlines intersect but are not parallel;
- Parallel misalignment where the shaft centerlines are parallel but not concentric; and
- Compound misalignment that involves a combination of parallel and angular misalignment. [Note: Almost all misalignment is compound misalignment, but practitioners talk about misalignment as the two separate types because it is easier to correct a misalignment by addressing the angular and parallel components separately.]

Impact: Premature wear on mechanical drive components that leads to premature failures
Instrument to measure and diagnose: Laser shaft alignment tool
Criticality: High

8. Shaft imbalance—Imbalance is a condition of a rotating part where the center of mass does not lie on the axis of rotation. In other words, there is a “heavy spot” somewhere on the rotor (see Figure 8). Although motor imbalance can never completely be eliminated, it can be identified when it is out of normal range, and action can be taken to rectify the problem. A vibration tester or analyzer can help determine whether or not a rotating machine is in balance. Imbalance can be caused by numerous factors, including:

- Dirt accumulation;
- Missing balance weights;
- Manufacturing variations; and
- Uneven mass in motor windings and other wear-related factors.

Impact: Premature wear in mechanical drive components that leads to premature failures
Instrument to measure and diagnose: Vibration tester
Criticality: High

9. Shaft looseness—Looseness occurs when there is excessive clearance between parts (see Figure 9). Looseness can occur in several places:

- Rotating looseness is caused by excessive clearance between rotating and stationary elements of the machine, such as in a bearing; and
- Non-rotating looseness happens between two normally stationary parts, such as a foot and a foundation, or a bearing housing and a machine.
As with all other sources of vibration, it is important to know how to identify looseness and resolve the issue to avoid losing money. A vibration tester or analyzer can determine whether or not a rotating machine is suffering from looseness.

**Impact:** Accelerated wear on rotating components resulting in mechanical failure

**Instrument to measure and diagnose:** Vibration tester

**Criticality:** High

10. **Bearing wear**—A failed bearing has increased drag, emits more heat, and has lower efficiency because of a mechanical, lubrication or wear problem (see Figure 10). Bearing failure can be caused by several things:
- A heavier-than-designed-for load;
- Inadequate or incorrect lubrication;
- Ineffective bearing sealing;
- Shaft misalignment;
- Incorrect fit;
- Normal wear; and
- Induced shaft voltages.

Once bearing failure begins, it also creates a cascade effect that accelerates motor failure. Learning how to troubleshoot this potential problem is important since 13% of motor failures are caused by bearing failure, and more than 60% of the mechanical failures in a facility are caused by bearing wear.

**Impact:** Accelerated wear on rotating components resulting in bearing failure

**Instrument to measure and diagnose:** Vibration tester

**Criticality:** High

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11. Soft foot—Soft foot refers to a condition in which the mounting feet of a motor or driven component are not even, or the mounting surface upon which the mounting feet sit is not even (see Figure 11). This condition can create a frustrating situation in which tightening the mounting bolts on the feet actually introduces new strains and misalignment. Soft foot is often manifested between two diagonally positioned mounting bolts, similar to the way that an uneven chair or table tends to rock in a diagonal direction. There are two kinds of soft foot:

→ Parallel soft foot occurs when one of the mounting feet sits higher than the other three; and

→ Angular soft foot occurs when one of the mounting feet is not parallel or “normal” to the mounting surface.

In both cases, soft foot can be caused either by an irregularity in the machine mounting feet or in the mounting foundation upon which the feet rest. In either case, any soft-foot condition must be discovered and remedied before proper shaft alignment can be achieved. A quality laser alignment tool can typically determine whether or not there is a soft-foot problem on a particular rotating machine.

Impact: Misalignment of mechanical drive components

Instrument to measure and diagnose: Laser shaft alignment tool

Criticality: Medium

12. Pipe strain—Pipe strain refers to the condition in which new stresses, strains, and forces acting on the rest of the equipment and infrastructure transfer backward onto the motor and drive to induce a misalignment condition (see Figure 12). The most common example of this is in simple motor/pump combinations, where something applies force to the pipeworks such as:

→ A newly installed valve or other component;

→ An object striking, bending or simply pressing on a pipe; and

→ Broken or lack of pipe hangers or wall-mounting hardware.

Those forces can put an angular or offset force on the pump, which in turn causes the motor/pump shaft to be misaligned. For this reason, it is important to check machine alignment more than just at the time of installation. Precision alignment is a temporary condition that can change over time.

Impact: Shaft misalignment and subsequent stresses on rotating components, leading to premature failures.

Instrument to measure and diagnose: Laser shaft alignment tool

Criticality: Low

13. Shaft voltage—When motor shaft voltages exceed the insulating capability of the bearing grease, flashover currents to the outer bearing will occur, causing pitting and grooving to the bearing races (see Figure 13). The first signs of this problem will be noise and overheating as the bearings begin to lose their original shape, and metal fragments mix with the grease and increase bearing friction. This can lead to bearing destruction within a few months of motor operation. Bearing failure is an expensive problem, both in terms of motor repair and downtime, so helping to prevent this by measuring shaft voltage and bearing current is an important diagnostic step. Shaft voltage is only present while the motor is energized and rotating. A carbon brush probe attachment allows the shaft voltage to be measured while a motor is rotating.

Impact: Arcing across bearing surfaces create pitting and fluting resulting in excessive vibration and eventual bearing failure.
Instrument to measure and diagnose: Isolated four-channel portable oscilloscope, with shaft voltage carbon brush probe  
Criticality: High

Four strategies for success
Motor control systems are being utilized in critical processes throughout manufacturing plants. Equipment failure can result in high monetary losses both from potential motor, or parts, replacement and from equipment downtime for the system the motor powers. Arming maintenance engineers and technicians with the right knowledge, prioritizing workload and managing preventive maintenance to monitor equipment and troubleshoot intermittent, elusive problems can, in some cases, avoid failures due to normal system operating stresses and reduce overall downtime costs.

There are four key strategies that can help restore or prevent premature failures in motor drive and rotating component:
1. Document operating condition, machine specifications and performance tolerance ranges;
2. Capture and document critical measurements at installation, before and after maintenance and on a routine basis;
3. Create an archive reference of measurements to facilitate trend analysis and identify change of state conditions; and
4. Plot individual measurements to establish a baseline trend. Any change in trend line of more than ±10% to 20% (or any other % determined, based on system performance or criticality) should be investigated to root cause to understand why the issue is occurring.

Hilton Hammond is Fluke Corp.’s Business Unit Manager for Power and Energy. He has deep familiarity with the full family of Fluke test tools, with particular expertise in power quality tools and ScopeMeter portable oscilloscopes. For more information, visit www.fluke.com.