BEARING CURRENT REMEDIATION OPTIONS

Sources, investigative measurements, and installation modifications to reduce damage as a result of bearing currents

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BEARING CURRENTS IN INDUCTION motors can result in premature bearing failure. In across-the-line driven electric motors, current-related bearing failures can occur due to a flow of current that is internally generated in the motor. The increased use of variable speed drives in industrial and commercial electric motor systems has raised the awareness of users as to a new source of bearing current flow that is externally sourced due to the switching characteristics of the inverter power source. Current paths within the motor and throughout the inverter-driven motor system must be well understood in order to apply effective bearing current remediation methods for these types of applications.

Effective remediation methods, for the relatively low percentage of inverter-driven motor installations where

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premature bearing failure due to electrical current flow occurs, rely upon a thorough understanding of the current flow paths within a given installation. Potential current flow paths should be identified before the system installation so that effective grounding, bonding, cabling methods, and motor modifications can be specified. For existing installations where damaging bearing currents are suspected, proper voltage and current measurement techniques with the right measurement equipment are key to obtaining a thorough understanding of the current flow paths and to the identification of bearing current remediation options.

Causes of Bearing Failures

The vast majority of bearing failures in electric motors and electric motor-driven equipment are due to mechanical and thermal causes. Potential causes of these types of failures include misalignment of the motor and load, vibration, incorrect lubrication, excessive radial or axial loading, lubricant contamination, or inadequate maintenance. In a small fraction of electric motor applications, bearings prematurely fail due to electrical causes.

Currents flowing through induction motor bearings have the potential of creating premature failure of these bearings. Figure 1 shows the typical fluting pattern in a bearing race due to metallurgical damage from interrupted electrical current flow. Increased noise and vibration are typical symptoms of bearing damage for a bearing such as this. Over time, lubrication fatigue and mechanical wear lead to ultimate bearing failure.

Bearing Currents in Inverter-Fed Electric Motor-Driven Systems

Bearing currents in sine-wave-driven motors are well understood [1]. These currents are either localized in the bearing or are driven through the bearing due to asymmetries in the motor material properties or construction. The low-frequency nature of bearing currents in sine-wave-driven motors results in current paths through what are generally considered to be conductive materials (motor shafts, frames, bearing races, and bearing balls). Interrupting the conducting current path with insulating materials (often referred to as *insulating bearings*) can eliminate these low-frequency bearing currents [2].

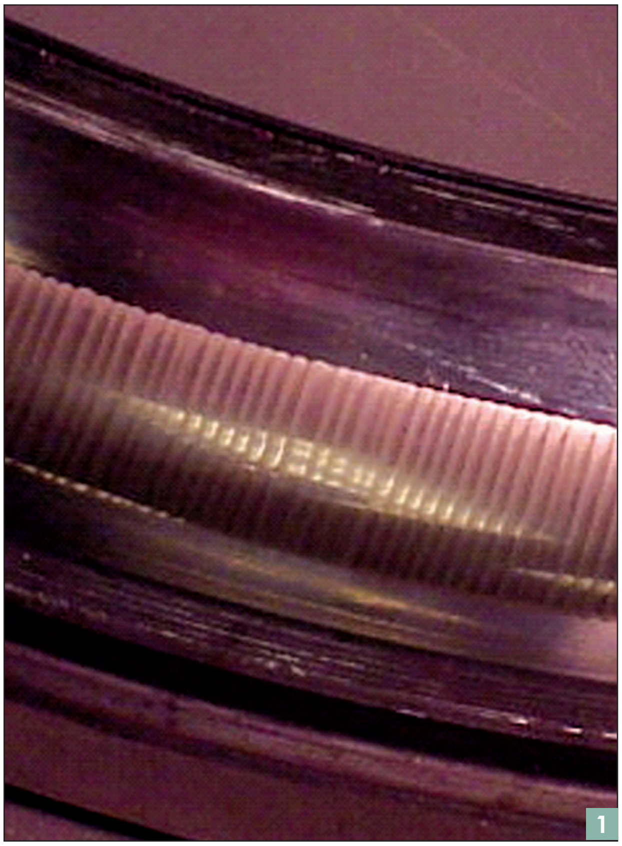
Electric motors powered by fast-switching pulsewidth modulated (PWM) voltage source inverters experience high-frequency voltage pulses with respect to motor ground [3]. At these high frequencies (up to several megahertz transitions) capacitively coupled currents can flow through paths that would normally be considered to be insulators. Currents now can flow through the magnet wire insulation, stator slot liners, motor air gap, bearing grease, and stator slot top sticks. These high-frequency current paths offer new opportunities for bearing current flow that can result in premature bearing failure. With inverter-driven motors, a clear understanding of high-frequency current paths from the motor terminals back to the inverter and to ground is key to determining potential bearing current problems and remedies. Current paths both internal to the motor and between the inverter, the motor, and the driven equipment must all be considered when looking for methods to reduce unwanted bearing current flow. Consequently, system-related issues—such as grounding and cable shielding—become very important to inverter-powered electric motor-bearing current remediation.

It should be pointed out that inverter-induced bearing currents have not been found to cause significant problems in the majority of applications. This article focuses on that small percentage of installations and applications in which damage as a result of bearing currents is possible. A large body of recent publications on various aspects of inverter-bearing currents exists ([3]–[8]). The present article hopes to furnish a practical solution-oriented presentation focused on the following three topics:

1) sine-wave- and inverter-driven motor bearing current root causes and current paths
2) field measurements of important voltages and currents to identify current flow paths
3) remediation methods at the motor and in the inverter-driven motor system for each possible current path.

Bearing Currents in Across-the-Line Powered Motors

Electric motor bearing currents are not new; in fact, they have been around since electric motors were invented. The most common underlying causes of unwanted bearing currents for sine-wave-driven motors is a lack of motor symmetry [1]. Perfect symmetry is difficult to achieve due to automated manufacturing methods and



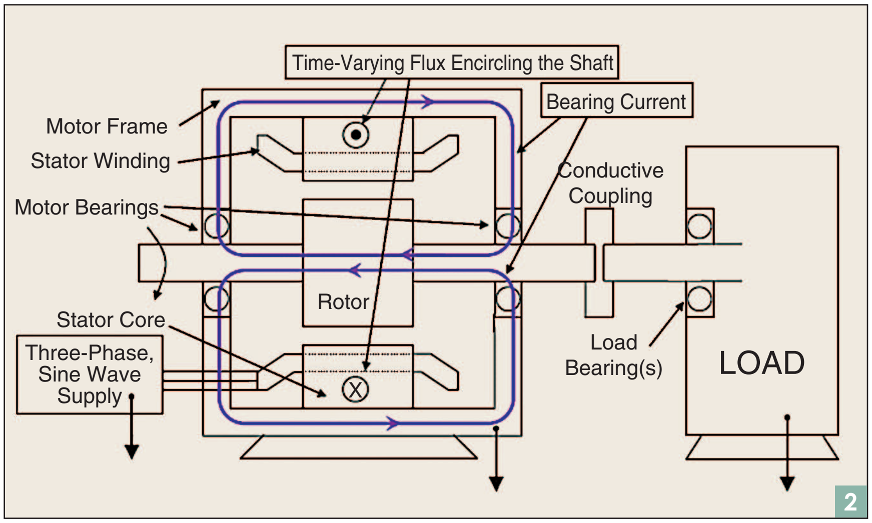
Bearing damage from prolonged running after metallurgical degradation due to current flow.

anisotropic properties of magnetic materials, such as electrical steel. The most common cause of bearing currents in sine-wave-driven motors is alternating flux linking the motor shaft as a result of asymmetrical magnetic properties of the stator or rotor core. Electric steel is not totally homogenous; therefore, flux paths in the motor are not entirely symmetrical. Asymmetrical flux through the steel results in time-varying flux lines that enclose the shaft. This can drive a current down the shaft, to the bearings, through the frame, and back again through the bearings, as shown in Figure 2. The resulting current is not localized within the bearing. Its driving voltage can be measured on motors with at least one bearing that is electrically insulated from the motor frame [2]. A worst-case estimate of bearing current resulting from this phenomenon can be obtained by measuring the shaft end-to-end current using an IEEE standard procedure [2].

The internally sourced, sine-wave-based bearing currents are most easily remedied by insulating one bearing, usually the opposite drive end bearing. This breaks the current path. Sine-wave (or low-frequency) bearing currents are also present in inverter-driven motors, and care must be taken to avoid reintroducing these low-frequency bearing currents into an inverter-driven motor system by misapplication of a shaft-to-frame grounding brush.

Common Mode Voltage in Inverter-Powered Motors

Inverter-driven motors have the potential for externally sourced bearing currents as a result of the voltage wave shape that is applied to the motor by the inverter. Modern voltage-source, PWM inverters switch a dc bus voltage (Vdc) onto the three phase terminals of the motor in a switching pattern that creates the proper fundamental component voltage and frequency. Since the motor line-to-line terminal voltage must be either +Vdc or −Vdc, it is not possible to have the three terminal voltages add to zero at all instants of time [3]. Most rectifiers that create the dc bus also introduce a common-mode voltage to the dc bus itself. The average voltage applied to the motor (over a cycle) is kept at zero, but the instantaneous sum of the voltages at the motor terminals is nonzero. This instantaneous voltage sum is called the common mode voltage (CMV), and it exists between the motor windings and the motor ground.

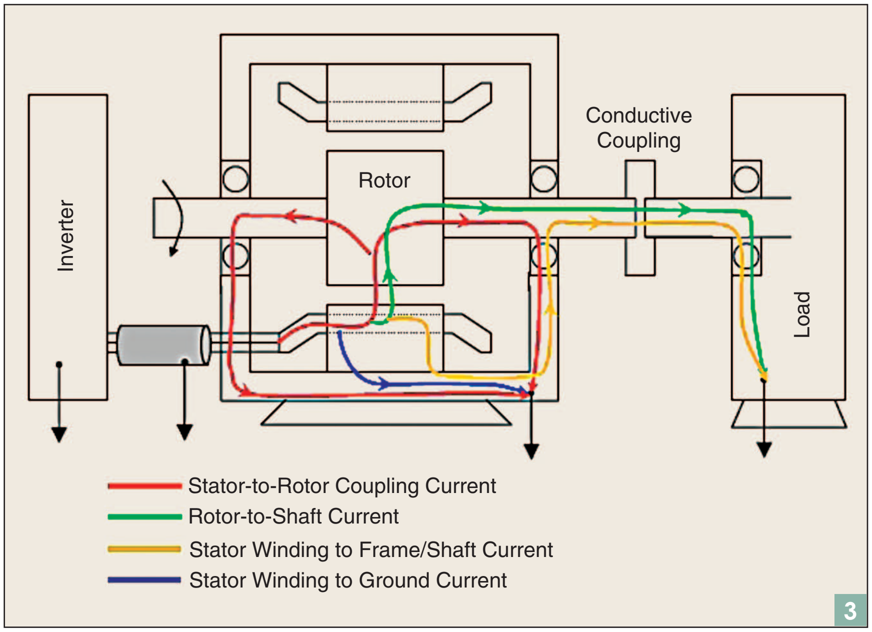


Time varying flux encircling the motor shaft can drive internally sourced currents through the motor bearings.

The CMV seen at the output of a low-voltage, voltage-source PWM inverter is a stair-step pattern with a fundamental frequency related to the PWM carrier. For medium-voltage current source inverters (CSI) the CMV is essentially a three-times line-frequency waveform whose amplitude is a function of load [4] so that for some operating conditions the motor is exposed to significant CMV.

Bearing Currents Resulting from CMV

For voltage or current source inverters, the CMV contains high rates of change of voltage with respect to time (i.e., high dV/dt), so its frequency content can be in the MHz range. Common mode currents (I) are created due to capacitive coupling of the CMV since $I = C\, dV/dt$, where C is the capacitance of the common mode circuit element.



Capacitively coupled current paths in an inverter driven induction motor system.

There are many potential current paths via this capacitive coupling from the motor stator winding to ground. Most of these paths are normally considered to be insulators; for example: stator slot liners, stator-to-rotor air gap, and the bearing lubricant film between race and ball. Figure 3 shows an inverter-driven motor system with the inverter connected to the motor through a shielded cable and the motor load connected to the motor shaft through a conductive coupling. The motor, cable shield, inverter, and load all have electrical grounds as indicated by the downward pointing arrows. All of these grounds are connected together in some fashion. In Figure 3, the various paths of capacitively coupled current are presented. The high dV/dt created in the stator winding couples capacitively with the stator core and frame and with the rotor.

The current path marked red is a capacitive current coupled to the rotor through the air gap, with a return path to the motor bearings, motor ground connection, and finally to the drive ground. Current flow through the bearing is a consequence of two phenomena. Conduction current may flow through the motor bearing if the shaft happens to be shorted to the frame (by bearing ball contact, for example) at the instant that the dV/dt transition occurs in the CMV. Discharge current may flow through the motor bearings if the bearing becomes conductive after first acting as an insulator. Discharge current may also occur when the voltage across the bearing lubricant film exceeds the film break-down voltage. The red current can not be directly measured without a specially instrumented motor since the entire current path is inside the motor.

The green (or rotor-to-shaft) current path in Figure 3 is also due to capacitively coupled current from the stator winding to the rotor across the air gap. This current component finds a path that passes through a conductive coupling, and through at least one load bearing, to the load ground and back to the drive ground. The same two bearing current phenomena discussed for the red current path can occur with the green current path, only now the conductive or insulating state of the load bearing will determine the type of current flow. The rotor-to-shaft current has the potential of creating damage in the load bearing or, for some types of couplings, the coupling itself. This current can be measured by putting a high-frequency current sensor around the motor shaft.

The gold (or stator winding to frame/shaft) current path in Figure 3 indicates a capacitively coupled current between the stator winding and the frame. As shown, this current flows through the stator winding insulation (which is capacitively conductive at high frequencies) and, with a poor motor-to-inverter high-frequency ground connection, flows through the motor frame, the motor bearing, the motor shaft, the conductive coupling, the load bearing, the load ground, and finally to the drive ground. Current through this path has the potential to damage the motor and load bearings, as well as the motor-to-load coupling. This current path would also include currents due to a transient voltage difference between the motor frame and the driven equipment.

The preferred path for all these currents, to reduce bearing damage, is the blue (or stator winding-to-ground) path in Figure 3. Here, no current flows through the motor or load bearings.

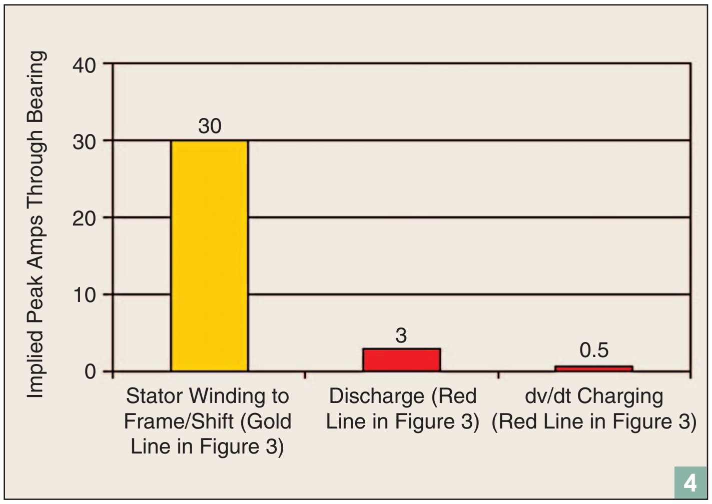
Currents Created by High-Frequency Encirculating Flux

The current paths shown in Figure 3 are shown as lumped circuit currents. In fact, the capacitively coupled current flow is distributed along the stator winding. This implies that current "leaks" from the winding over the length of the winding, so that the axially directed current at the winding input is larger than at the winding exit point [5]. The result of this phenomenon is a net axial current flow down the entire stator winding. There is also a simultaneous drawing of current to the stator core and stator frame that represents the current that has bled from the stator winding due to capacitive coupling. The combination of these events creates an encirculating flux and a high-frequency current flow down the shaft, through the bearings and the motor frame along the same path as shown in Figure 2. This current may have the potential to damage the motor bearings. This type of current is neither well understood nor easy to measure.

The relative magnitude of some of the various current components shown in Figure 3 is shown in Figure 4. As shown, the largest potential inverter-induced bearing current is the stator winding-to-frame shaft current in Figure 3, the magnitude of which is ten to 60 times as large as the other components.

Measurement Goals for Bearing Current Identification

Current flow through the bearings in electric motor systems has been shown to have a variety of potential paths. Methods to reduce or eliminate damaging bearing currents depend upon which path is dominant in a particular application. Some voltage and current measurements, with careful measurement techniques, can result in the identification of the sources of bearing current flow and, in some cases, the path of this flow.



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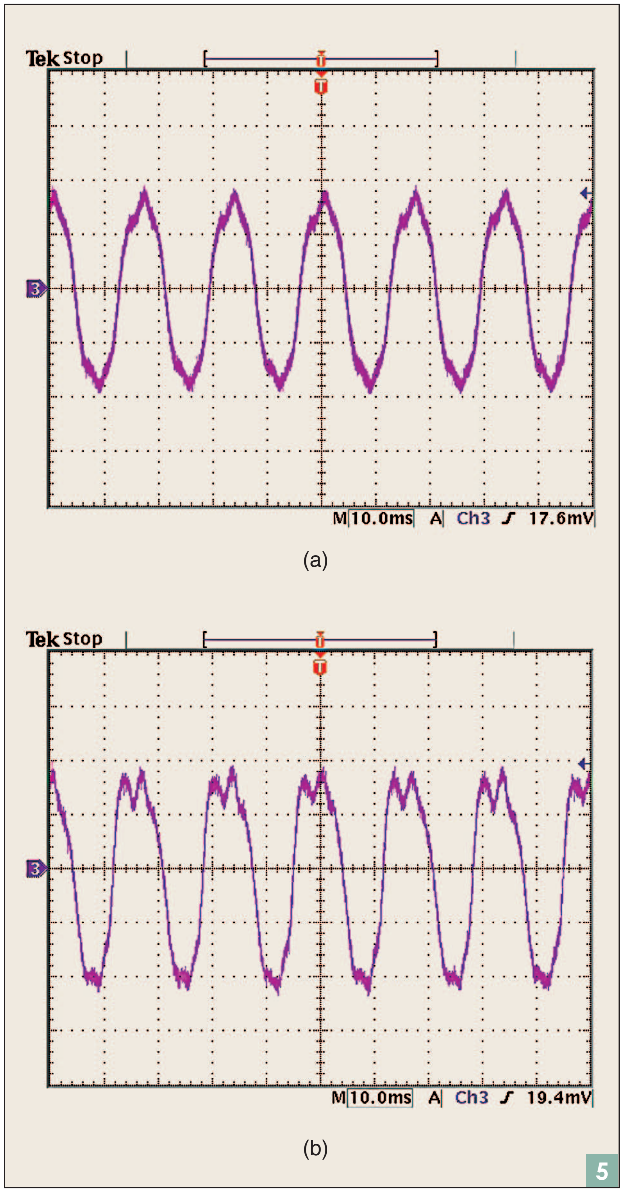
Motor bearing current relative magnitudes.

The measurement of bearing currents presents significant challenges. Most of this difficulty arises because it is not practical to place a transducer in the part of the bearing where the current actually flows. Additionally, the current can flow as a brief impulse—as might occur in the discharge of a capacitor. Therefore, field measurements are largely relegated to methods that will provide insight into *symptoms* of potential bearing current problems. Many field measurements are done after bearing damage has occurred, where causes are being determined so that the proper remedial action can be taken.

A key goal of the measurements is to segregate any bearing currents by identification of the type and source. Each type of bearing current has its own measurement and interpretation. The measurement of the potential for end-to-end circulating currents would be done in order to determine any tendency for internally sourced bearing currents (inverter independent). In order to check for "discharge"-type bearing currents, a measurement can be made of the voltage across the motor bearings (shaft-to-ground voltage). Ground potential equalization currents can be detected through the measurement of current in the motor shaft extension. Finally, a secondary check for ground currents that may take a path through bearings can be made by measuring the common mode current (CMC) entering the motor on the power leads and simultaneously observing the motor ground conductor currents.



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(a) Unsaturated and (b) saturated conditions, end-to-end current in short circuiting conductor, 5 A/div.

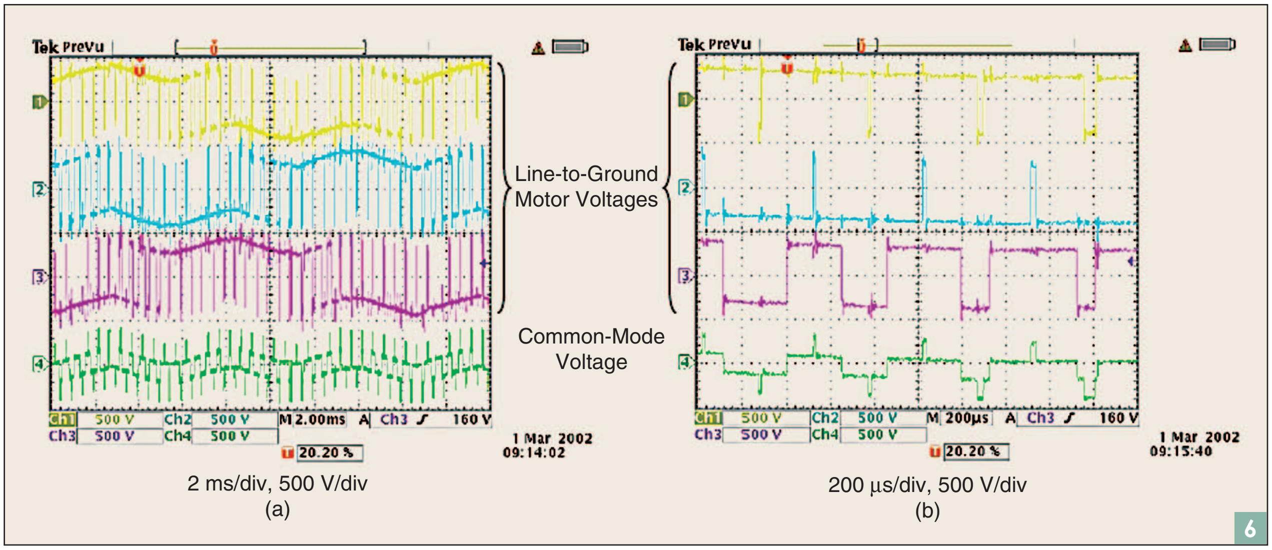
Measurement Examples and Interpretations

An example of a measurement of motor end-to-end circulating current potential magnitude is seen in Figure 5. With a low resistance short circuit, the maximum possible end-to-end current can be quantified. This is clearly a low-frequency current, with some increase in harmonic content for higher (magnetic) saturation levels [Figure 5(b)]. These currents can be satisfactorily quantified with simple 50–60 Hz measurement instruments. Typical limits on end-to-end short-circuit currents are in the range of 30 A peak or 20 A rms.

Since the source of the high-frequency bearing currents is the CMV transitions from the inverter, it is useful to reference all system measurements to the CMV waveform. Shaft-to-ground voltage measurement (both magnitude and wave shape) provides insight into potential (discharge-type) bearing current flows. CMV measurement is usually done by creating an artificial neutral for the three phase voltages applied to the motor terminals. Three symmetric high-resistance (and low-inductance) resistors are connected in a Y arrangement. One end of each resistor is connected to the three phase leads. The measurement is taken from the center point of this resistor Y to the motor ground. Figure 6 shows motor line to ground and CMV for a typical 460-V, inverter-driven motor. Note that CMV transitions occur at each line-to-ground phase voltage transition. The actual wave shape of the CMV is a function of the inverter switching pattern for the motor operating condition as well as the time instant in the inverter output voltage waveform.

The CMV is to be used as a reference for shaft voltage and CMC measurements, so it is usually displayed on one of the scope channels for all further measurements on the motor system. The rise time and overshoot of the CMV provides insight into the level of dV/dt and peak CMV of this motor/inverter system.

Motor-shaft to frame-voltage measurements are made with a brush or pickup that can make contact with the shaft while in motion. The shaft voltage is measured relative to a ground reference point. The ground point should be as close as possible to the bearing outer race. A high-frequency oscilloscope is required, combined with a high-voltage, high-frequency probe. Among the challenges in measuring shaft-to-frame voltage is that the bearings exhibit a significantly stochastic behavior. Bearings change from insulating mode to conducting mode in a somewhat random fashion and in response to applied voltage. Additionally, the PWM transitions are not all identical. If the turn-on time of a transistor is nominally 50 ns, the actual turn-on time might be 50 ns in one instance and 150 ns in



2 ms/div, 500 V/div
(a)

200 µs/div, 500 V/div
(b)

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(a) Line-to-ground voltage and (b) CMV for a PMW inverter-driven 460-V motor.

another. Since each transition is different, the scope should be dc triggered and with the trigger level set to display the highest voltage excursions in order to measure the *maximum* voltage across the bearing.

Comparing the bearing voltages (trace 2) of Figures 7 and 8, it can be seen that when a bearing becomes "conducting" and then "insulating" at inopportune times (relative to the CMV transitions), the voltage across the bearing can then charge up to twice the "normal" level (had it merely mirrored the CMV).

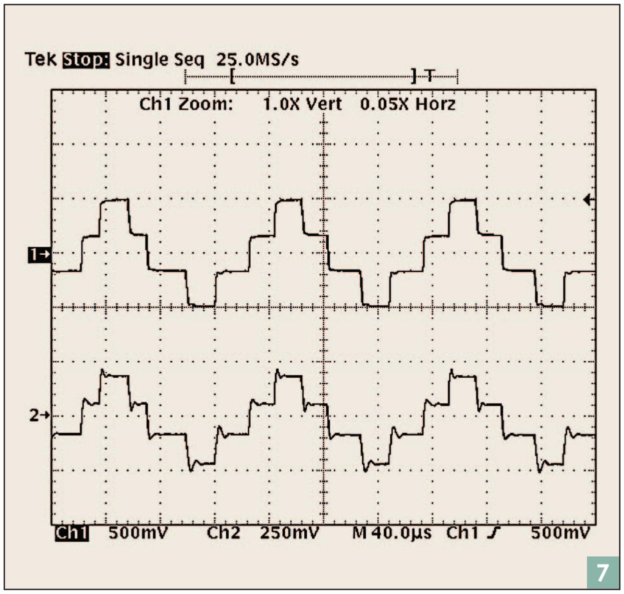
The traces of Figure 9 show the same bearing voltage phenomenon, except for a medium-voltage inverter system.

The bearing voltage may exhibit one of several possible phenomena. If current through the bearing due to CMV is infrequent, the shaft-to-frame voltage wave shape will mimic the CMV wave shape (but with reduced amplitude) for most time ranges. In this case, there may be sudden occurrences of zero shaft-to-frame voltage after a voltage chargeup (see Figure 8 at 136 μs), which implies a bearing conducting mode and a pulse of bearing current. The current that flows at the instant of this transition may damage the bearing. It is important to note that a bearing may remain nonconducting at a voltage of 22 V (trigger point of Figure 8), yet "short out" at less than half that voltage magnitude (136 μs point of Figure 8). Observation of many traces over a period of time may be required to determine the bearing behavior.

In some cases, the shaft-to-frame voltage wave shape will show instances of mostly zero voltage with attempts to charge up. This implies that the bearing may be staying in a conducting mode so that the rotor does not build up a substantial voltage.

Current down the output shaft of the motor (Figure 10) is also important to measure. This can be done using a high-frequency response current transducer. Any measured current indicates bearing current flow either in the motor bearing or a bearing of the coupled equipment, or both. The lower trace of Figure 10 shows a spike of 30 A in a motor shaft extension. This can imply that the ground return for CMC is not of sufficiently low impedance to keep the motor frame from instantaneously having a nonzero voltage. The resultant differential voltage from the motor frame to the coupled equipment can be "shorted out" by the shaft extension and associated bearings. This is a source of potentially high magnitude bearing current (see Figure 4).

CMC measurements are made to determine if current flow is occurring in undesirable paths. Undesired paths include through the motor bearing and/or the motor shaft extension into coupled equipment. CMC into the motor is the instantaneous sum of the three phase currents. CMC flows into the motor from the inverter and eventually returns back to the inverter. The preferred return path (as mentioned above) is through a low-impedance ground conductor from the motor to the inverter. The CMC into the motor can be measured by placing a current transducer



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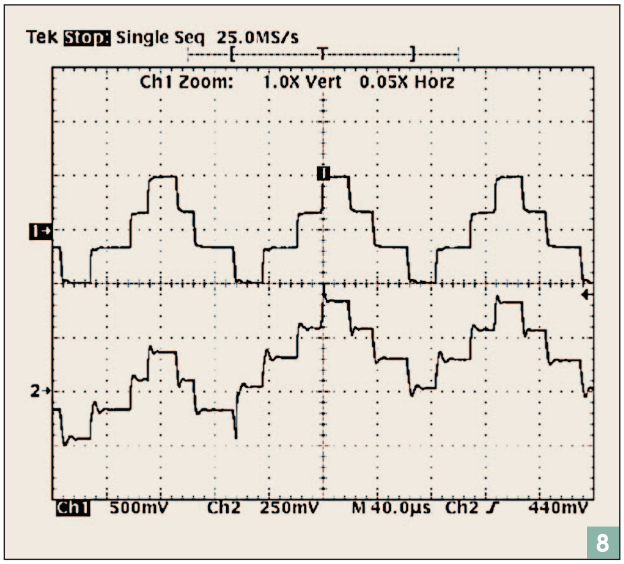
Common mode voltage and bearing voltage (without bearing conduction) Ch 1: 250 V/div, Ch 2: 12.5 V/div.

around the three motor power leads (without enclosing ground leads, shields, etc.). By comparing this measurement to the current through the ground conductors (including the conductor shields), stray CMC can be determined. The ground conductors should carry all of the CMC. Figure 11 shows measured CMC into a motor. CMC pulses occur at each transition of the CMV (the dV/dt capacitively coupled effects). A difference between the ground conductor current and the common mode input current can imply a grounding system problem.



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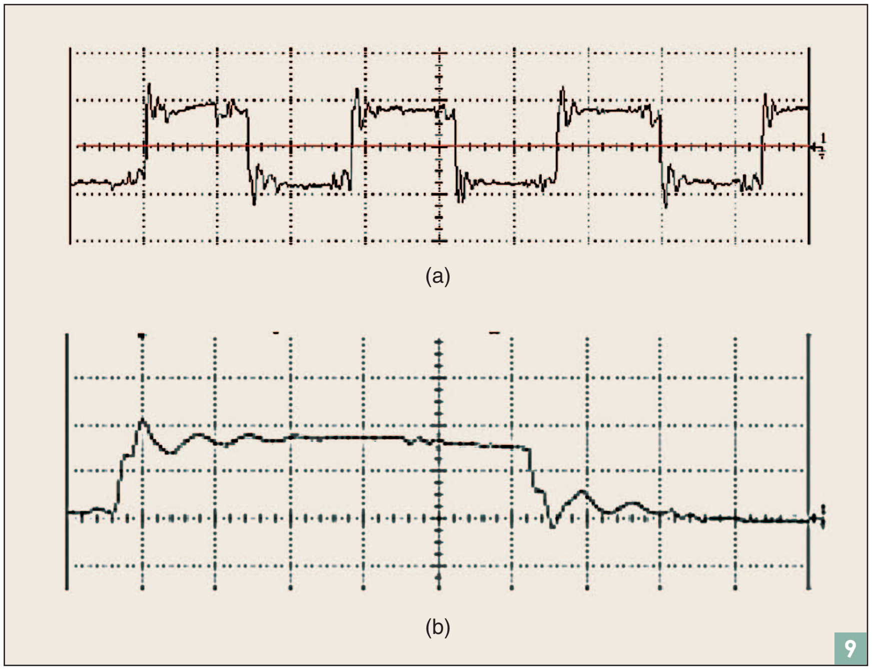
Common mode voltage and bearing voltage (with bearing transitions between insulating and conducting modes) Ch 1: 250 V/div, Ch 2: 12.5 V/div.



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(a) Shaft voltage-to-ground 200 V/div; 2 ms/div, 4160 VAC CSI inverter system, no bearing conduction observed. (b) Shaft voltage-to-ground, 200 V/div; 0.5 ms/div, 4160 VAC CSI inverter system, double magnitude (400 V) bearing voltage.

Instrumentation and Data Acquisition for Inverter-Driven Motor-Bearing Current Investigations

While it has been previously pointed out that the measurements on PWM power must be made with instrumentation capable of operating at high frequency, the test "techniques" can be equally important in obtaining meaningful measurements. The choice of which trace to use to trigger the scope, as well as the type of triggering and set point, can significantly alter the recorded waveforms.

Since it is typical to document the largest magnitude signals (currents and voltages), the scope triggering should be adjusted to detect these signals. A common technique is to use dc triggering, setting the trigger level high enough so that no triggering occurs initially. The trigger level is then incrementally reduced until triggering just occasionally occurs. Because of the signals not being truly "repetitive" (identical), it is common to take readings with each of the desired signals providing the "trigger" function.

The fact that the signals are not identical from pulse to pulse also means that the scope capabilities should be examined for the condition of "single-shot" rather than repetitive bandwidth. While it is tempting to try to display a full fundamental cycle on a scope, the long time record that this represents would degrade the actual sampling rate (and, thereby, the bandwidth) for the measurement. Note that in Figures 6 through 11 the typical time base is in the range of 5–200 μs/division.

Bearing Current Remediation Methods

The various bearing current paths that can exist in a sine-wave or inverter-driven induction motor system are shown in Figures 2 and 3. A number of solutions are available to reduce or eliminate these current flows, the appropriateness of each depending upon the type and source of the bearing current found. For inverter-driven motors, eliminating or reducing the CMV and current addresses the problem at its source [6]. This, however, is a drive design issue and therefore cannot be easily addressed in existing applications, so it will not be further considered here.

Table 1 lists bearing current remediation methods for the various current paths. If multiple current paths are expected in a given application, multiple remediation methods may be required to eliminate potential bearing damaging current flow. Methods that are available are:

- improve high-frequency grounding connection from the motor to the drive and from the motor to the driven equipment

- one insulated bearing on the opposite drive end of the motor
- two insulated bearings on the motor
- shaft grounding brush across one motor bearing
- Faraday shielded motor [8]
- insulated coupling between the motor and the driven equipment.

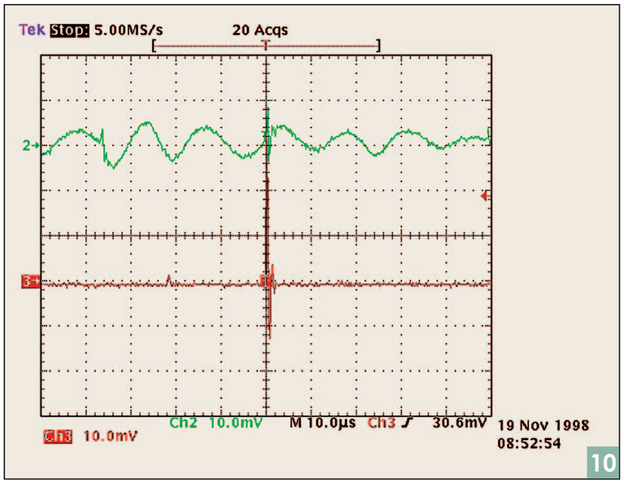
Improved grounding of the inverter-driven motor system is a key component of many inverter-induced bearing current remediation methods. Figure 3 shows various locations throughout an inverter-driven motor system that are connected to ground. In a real motor installation there is nonzero ground impedance between the various ground points. It is important to provide low impedance grounding paths between these points so that CMC is kept away from motor or driven load bearings.

One important ground current path connection is between the motor and the inverter. Cables that provide continuous, low resistivity shielding around the three phase conductors provide the lowest motor CMC and motor frame voltage [7]. Continuous corrugated aluminum sheathed cables provide this optimum performance and are highly recommended for motor/inverter installations. The continuous aluminum sheath provides low resistance and low inductance, an important feature that results in minimum high-frequency impedance. Optimum cable performance is obtained when the cable sheath is connected to the motor frame and drive cabinet through a low impedance path. Cable connectors that provide 360° surface contact between the cable sheath and the connector and the connector and the motor and drive frame are recommended to provide this low impedance path. The ground conductor(s) within the cable should ideally be symmetrically spaced with respect to the three power conductors. Connection of both the shield/sheath, as well as the ground conductors at both the motor and the inverter ends, creates a low impedance path for (high-frequency) pulses of CMC. The termination of the ground conductors and the sheath/shield should avoid adding impedance in the connections by landing these connections on a prepared ground surface intended for this purpose; one free of paint or in a current path that may contain insulating materials such as gaskets or seals.

Proper grounding of the motor frame is also important. Capacitively coupled currents from the stator winding to the motor frame are the largest potential component of bearing current in applications with conductive shaft couplings (see Figure 4). Besides the cable's low impedance ground path from the motor to the inverter, ground straps should also be connected between the motor frame and the driven load equipment frame to allow a low-impedance, alternate path for shaft currents. This is particularly important in applications where a conductive coupling connects the motor shaft to the driven equipment and where the motor and driven equipment are not on a common metal baseplate. High-frequency ground strap impedance is lowest for straps with fine conductors and the largest width-to-length ratio. Therefore, the widest ground strap that is practical should be used for this ground connection. In all cases, ground straps should be connected directly metal to metal (not through a painted surface) to provide the lowest impedance path for high-frequency currents.

Table 1 lists remedies for various bearing current types. Each row in the table corresponds to a type of shaft and bearing current. Each column represents a potential solution. An **X** in the table indicates that the remedy, by itself, will reduce or eliminate bearing damage due to that particular component of bearing current. As is shown in the table, no single motor construction or system installation method will remedy all bearing current components. Also, note that some remediation methods may reduce currents in one part of the system while increasing damaging current flow in other parts of the system.

One combination of remedies that reduces or eliminates all bearing current flow is shown in Figure 12. Here an opposite drive-end insulated bearing, a drive-end shaft-grounding brush, and good high-frequency grounding between the motor and inverter and between the motor and the driven equipment is used. Each remedy employed acts to either interrupt a potential damaging current path (insulated bearing) or redirect the current away from the bearing



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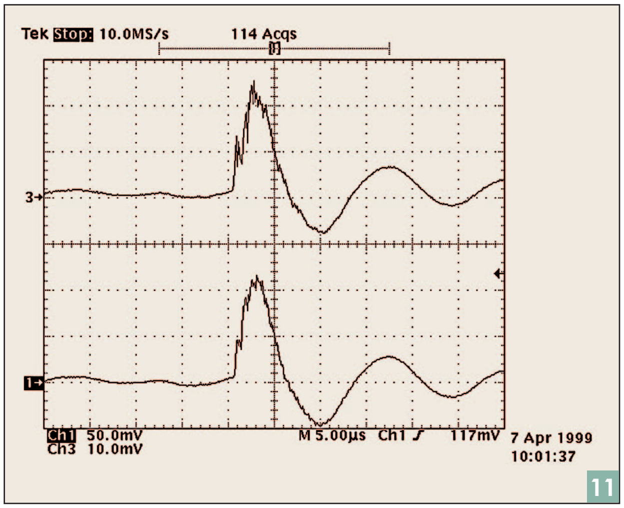
Shaft extension current (lower trace), 10 A/div.



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Common mode current (lower trace) and ground conductor current (upper trace). Both traces are 5 A/div.

TABLE 1. REMEDIATION METHODS FOR BEARING CURRENTS IN INDUCTION MOTOR SYSTEMS.

Remedy → *Source of Current*	Well-terminated cable ground connections—drive to motor	Bonding strap between motor and load frame	One insulated motor bearing on opposite drive end	Two insulated motor bearings	Shaft grounding brush across one motor bearing	Faraday shield	Insulated coupling between motor and load shaft
Internal, circulating, due to magnetic asymmetry leading to net flux linking shaft (fundamental frequency or sine wave). Generally occurs on motors above NEMA 400 frame (see Figure 2.)			X	X	Avoid without opposite bearing insulated		
Common mode (ground) current (induced by common mode dV/dt) taking a return path via the motor shaft extension and coupled equipment (gold current of Figure 3).	X	X		X	Avoid without insulated coupling or bonding strap between motor and load to protect driven equip.		X
Discharge through motor or load bearing of the shaft voltage. This shaft voltage is capacitively-coupled to the common mode voltage (red and green current in Figure 3).		Only if in combination with motor shaft ground brush		Only if in combination with motor shaft ground brush or insulated coupling	X	X	May cause increased motor bearing current without motor shaft ground brush, Faraday shield, or insulated motor bearings

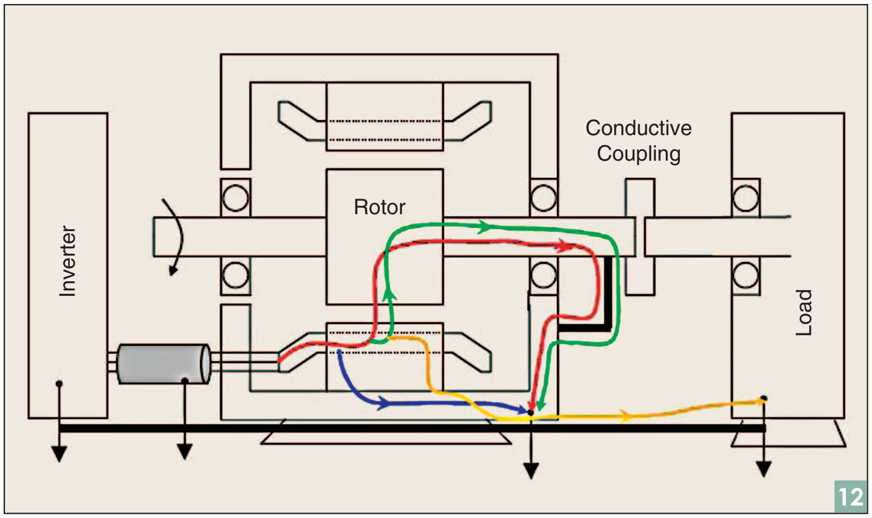
X indicates that the remedy will, by itself, reduce or eliminate motor bearing current damage *and* current flow to coupled equipment.

by providing a lower-impedance path (shaft brush and improved ground connection).

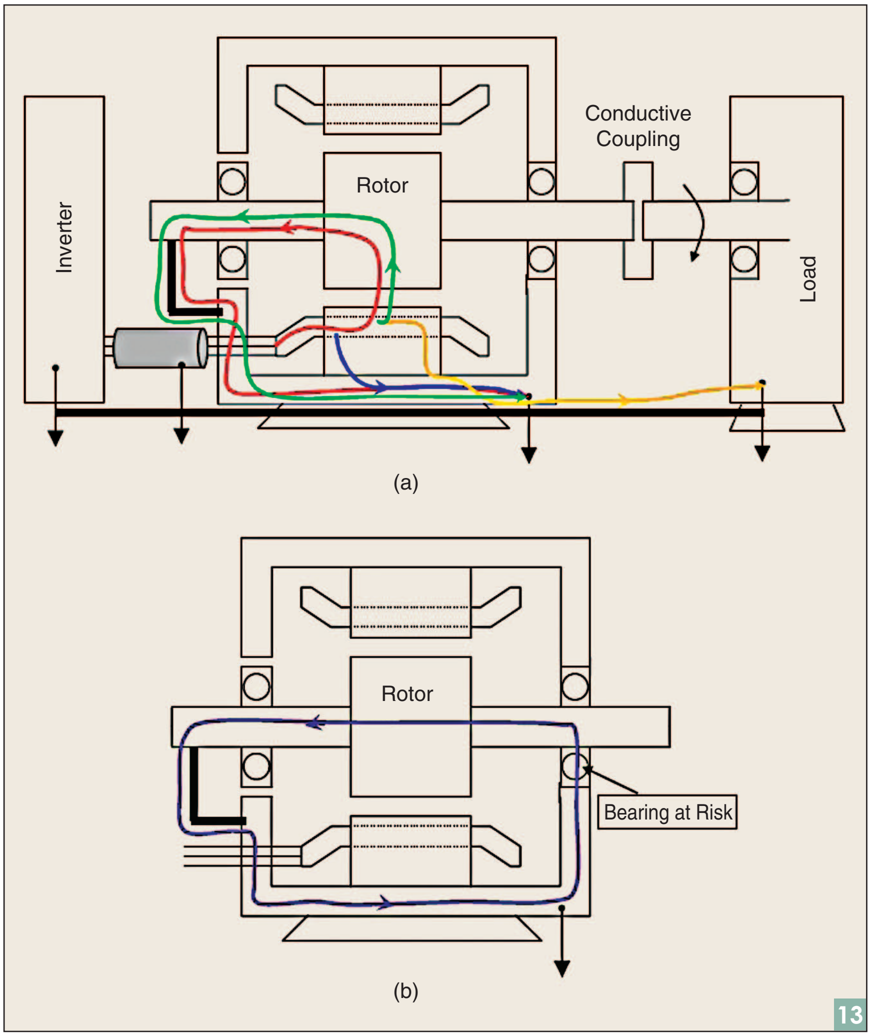
In existing installations, it is important to consider the entire system and all of the potential current paths that may exist before a solution is implemented. It is common to add a shaft-grounding brush to the motor when bearing damage has occurred and inverter-induced currents are suspected. Note, from Table 1, that the addition of a shaft-grounding brush may ultimately increase bearing current flow somewhere else in the system. For internal circulating currents (fundamental frequency or sine wave), the addition of a shaft-grounding brush to a motor without insulated bearings may greatly reduce the impedance seen by this current (see Figures 2 and 13). The result could be increased circulating current and bearing failure on the bearing opposite the shaft-grounding brush. Also, if a shaft-grounding brush is inadvertently placed across an insulated bearing, as shown in Figure 13, circulating currents may now increase and again put the opposite bearing in jeopardy. Some speed or position feedback devices may include shaft grounding as an option. Before these are added to a system, it is best to determine if the motor has insulated bearings.

The addition of a shaft-grounding brush in the system of Figure 12 must also be done with care. Note that if the ground strap from the motor to the load is removed, then shaft extension current may flow through the installed shaft brush, down the shaft, and to the driven equipment bearings. In this case, the bonding strap is very important so that shaft current flow can be shunted to the ground strap and avoid both driven equipment bearing and possibly conductive coupling damage.

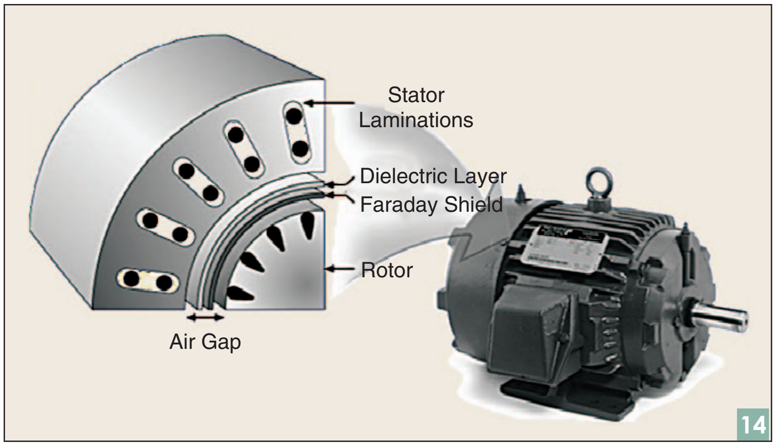
On existing installations where potential bearing current damage is of concern, the remedies will depend upon the current flow paths. In some cases, measurements of shaft voltage and/or current—CMC or net cable current, as described in this article—will offer insight into what current



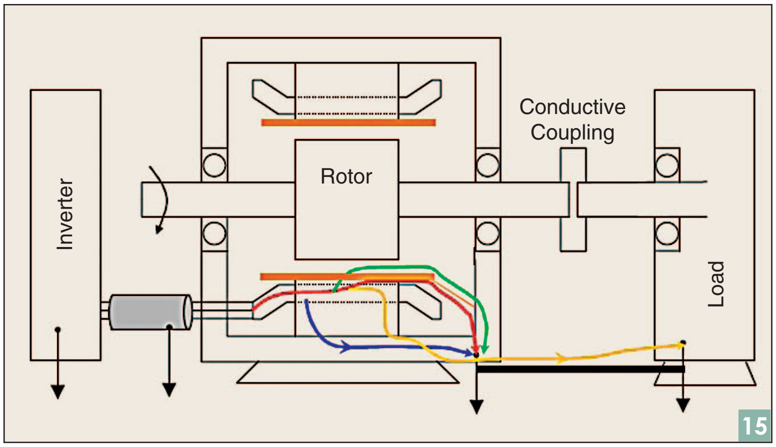
One insulated bearing and shaft grounding brush and motor good high-frequency grounding from motor to load and from motor to drive. This solution reduces or eliminates all bearing current components both sine wave and inverter induced.



Shaft grounding brush across insulated bearing that (a) eliminates inverter induced bearings currents but (b) increases internally generated bearing currents in uninsulated bearing.



A Faraday shield added to the induction motor stator reduces voltage induced on the motor shaft.



Faraday shielded induction motor to eliminate stator to rotor coupling across the air gap.

components exist in the system. Once the current paths are identified, Table 1 can be used to determine the proper retrofit solution. For example, consider an installation where shaft current is measured between the motor and the connected equipment. If the motor has one insulated-bearing and a shaft-grounding brush, the remedy would be to add a bonding strap from the motor to the load or improve the ground connection between the motor and the inverter.

In installations where rotor voltage buildup and discharge is of primary concern, a Faraday shielded motor [8] will provide protection from motor-bearing current damage. Figure 14 shows the Faraday shield concept as it applies to electric motor manufacture. Figure 15 shows the current paths with the Faraday shield motor in the inverter-driven motor system. In this motor a grounded conductive layer is placed in the motor air gap, usually on the stator inner surface. This conductive layer reduces the capacitively coupled currents crossing the motor air gap, thereby greatly reducing the motor shaft voltage. In applications where shaft current flow may be present, it is important to include good grounding between the motor and inverter and the driven equipment and motor since the Faraday shield does not reduce current flow from the stator winding through the motor bearing down the shaft.

Conclusions

Bearing currents in electric motors are not new. Internally sourced circulating currents within the motor have been known to exist on sine-wave-driven motors for many years. Externally sourced, inverter-induced bearing currents due to CMV are new and present new challenges. Fortunately, these CMV-induced bearing currents are not seen in a vast majority of inverter-driven motor applications.

Proper remediation methods depend upon a thorough understanding of the potential current paths in a given installation. Diagrams of current flow paths were presented here to illustrate potential issues. Test methods to determine these current paths were presented here as well. Once the types of currents that exist in a given system are known, remedies were presented for each one. Proper grounding is a key to shunting currents away from paths that flow through motor or driven equipment bearings. It was pointed out that caution should be taken when adding a shaft-grounding brush to an inverter-driven motor bearing in order to prevent increased current flow through other bearings in the system.

Elimination of bearing damage in inverter-driven motors requires a thorough understanding of the inverter/motor/driven equipment system. High-frequency current paths are not always easy to identify, but proper identification is key to providing an appropriate remediation method.

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