technical brief

Bearing Currents: A Major Source of Mechanical Failure for Motors in Adjustable Speed Drive Applications

Energy Delivery & Utilization Division
New Electric Motor/Drive Markets and Solutions Target

Shaft voltage, bearing currents, and the resulting motor bearing failures have been reported since early this century. Before adjustable speed drives (ASDs) were widely applied in industries, shaft voltage and bearing currents were mainly the result of magnetic field dissymmetries in the motor air gap. With improvements in machine design and manufacturing technology, shaft voltage and bearing current problems were thought to be under control and not a main concern for motor manufacturers and customers. However, in the past 20 years, industrial controls have experienced dramatic changes with advances in ASD technology. The introduction of the fast-switching semiconductor devices, such as the insulated gate bipolar transistors (IGBT) into PWM inverter manufacturing, has further improved pulse-width modulation (PWM) ASD performance. However, the shaft voltage and bearing current problems have resurfaced due to the high switching frequency and high dv/dt created by fast switching. An increased report of premature bearing failures has once again attracted the attention of motor and drive manufacturers and their customers.

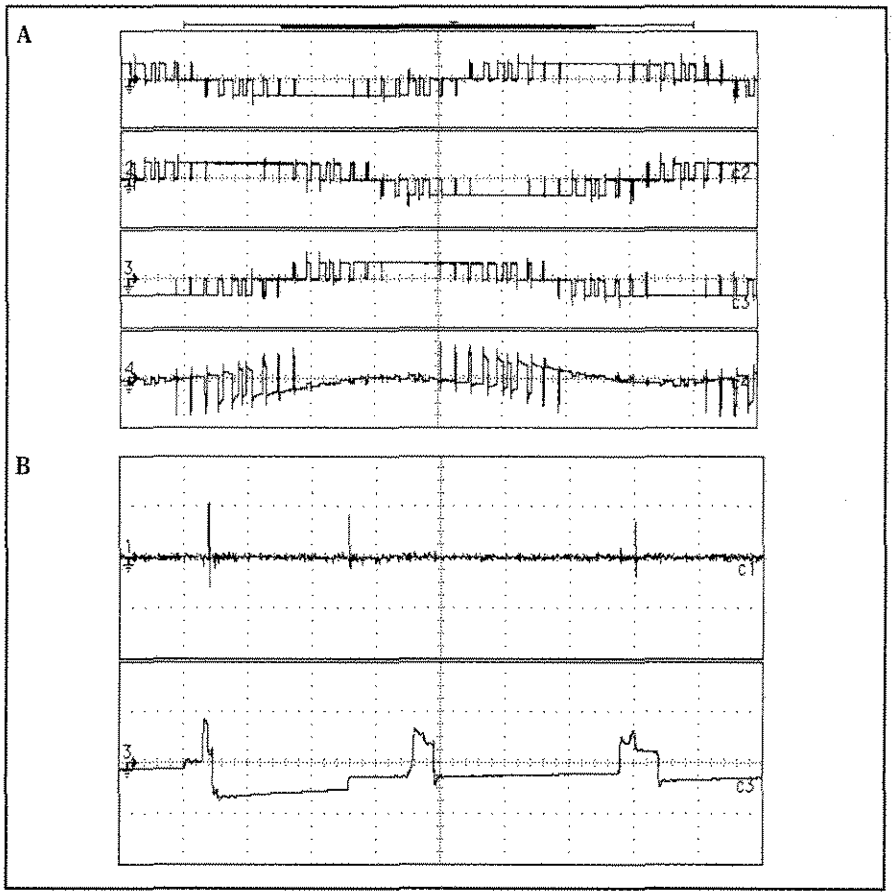

Figure 1. 5 hp, 460 V (A) (Ch. 1–3) PWM motor input voltages (L-L, 500 V/div), (Ch. 4) shaft voltage (10 V/div) (B) Outboard bearing current (50 mA/div), and shaft voltage (10 V/div).

Causes of Bearing Currents and Bearing Failures for Motors in PWM ASD Operations

In addition to magnetic dissymmetries, other causes for bearing currents include voltage potential accidentally applied to the shaft, electrostatic charge accumulation, shaft magnetization effects due to unbalanced ampere turns, and common-mode voltages (voltage potentials relative to a common reference point or ground) generated by unbalanced excitation of the motor windings. Any one of these could cause bearing currents and bearing failures, depending on the operating condition, motor control method, and motor and drive type and rating. The combination of these problems would likely create the worst-case scenario. Recently, common-mode voltages with high frequency and high dv/dt have been found to be the major cause of bearing currents and premature bearing failures in high-frequency PWM inverter-fed induction motors. Modern PWM inverters inherently generate alternating common-mode voltages within the motor windings that cause electrostatic (capacitive) coupling between the rotor and the stator windings and the frame, enabling voltage build up on the motor shaft. Since the grease inside the bearings has a partial insulating effect when the motor is running at high speeds, the bearing balls are not in electrical contact with the inner and outer race. Therefore, the charge accumulates on the rotor assembly, including the inner races, until it exceeds the dielectric capability of the bearing grease. The resulting effect is a frequently repeated flashover current up to several hundred milliamps to several amps in magnitude, depending on the motor and the drive (Figure 1). In time, this current can damage the bearing surfaces due to the electric discharge machining (EDM) effect, or electroplating of the race steel and bearing balls (pitting). The deterioration will appear as fluting (grooves) in the bearing race for motors running at relatively constant speeds, and as frosting on the race surfaces for motors operating over a wide speed range. The first signs of deterioration will be noisy bearings as the bearing friction increases and liberates wearing metal particles into the lubricant. This can lead to bearing destruction within a few months of ASD operation and is thus expensive in motor repair and downtime. Motor reliability statistics show that bearing failures account for 40% of the total motor failures and almost 25% of all bearing failures were due to high-frequency switching and high dv/dt.

Although common-mode voltage is inherent in conventional PWM inverters, it is possible to prevent shaft voltages and/or bearing currents through a variety of mitigation techniques.

Using a Shaft Grounding Device to Bypass Bearing Currents

The shaft grounding device provides a low impedance parallel path from the motor shaft to the frame, which successfully eliminates shaft voltage and therefore bearing currents. The grounding brush is self contained for clean-room environments. The brush typically requires maintenance after 2–3 years of operation, but is a reliable and comparably low cost means of protecting the motor bearings from destructive bearing currents. The grounding device, which is currently on the market, can be retrofitted to virtually any motor shaft (Figure 2).

Isolating the Shaft From the Motor Frame

Isolating the shaft will eliminate the current path through the bearings and thus offer protection. However, this method may not be acceptable if the motor drives loads with its own bearings or if a tachometer is used, since the shaft voltage still exists and could find another damaging path to ground.

Ceramic bearings can be used to isolate the shaft from the frame. Ceramic bearings are a combination of nonmagnetic and electrically insulating ceramic balls and bearing-quality steel rings. Thus, the current path from the shaft to ground is eliminated (Figure 3). At this time, motors ordered with ceramic bearings are expensive and have long lead times.

By insulating the journal on the outboard bearing (i.e., with aluminum oxide) or insulating both bearings (i.e., with a resin coating) the circulating current path can be broken. However, this insulation may not function properly for PWM ASD operations. The insulator coating must be thick enough to significantly reduce the capacitance between the shaft and the inner bearing race. Otherwise, this capacitance could provide a low impedance path for shaft voltages. In addition, the insulator may become compromised by contaminants and thus conduct currents. The user can request the journal or bearings be insulated during the manufacturing process, but the cost typically precludes this application for motors less than 200 hp.

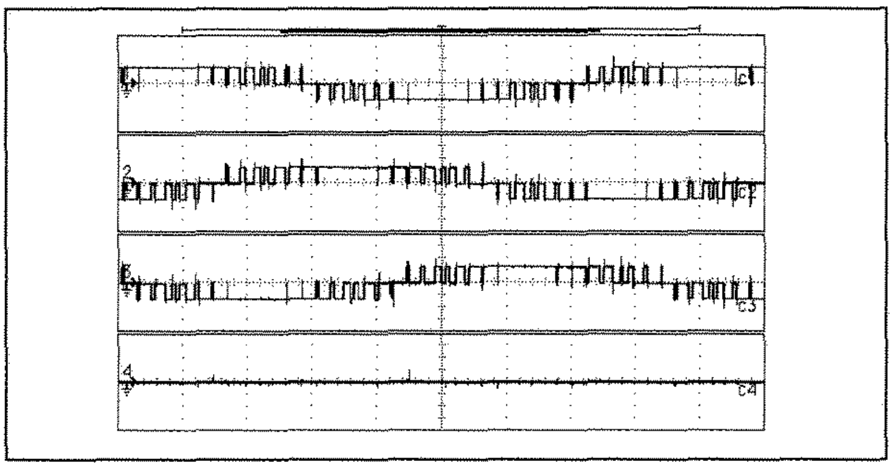

Figure 2. 5 hp, 460 V, (Ch. 1–3) PWM motor input voltages (L-L, 500 V/div), (Ch. 4) shaft voltage (negligible) **with shaft grounding system (4 V/div).**

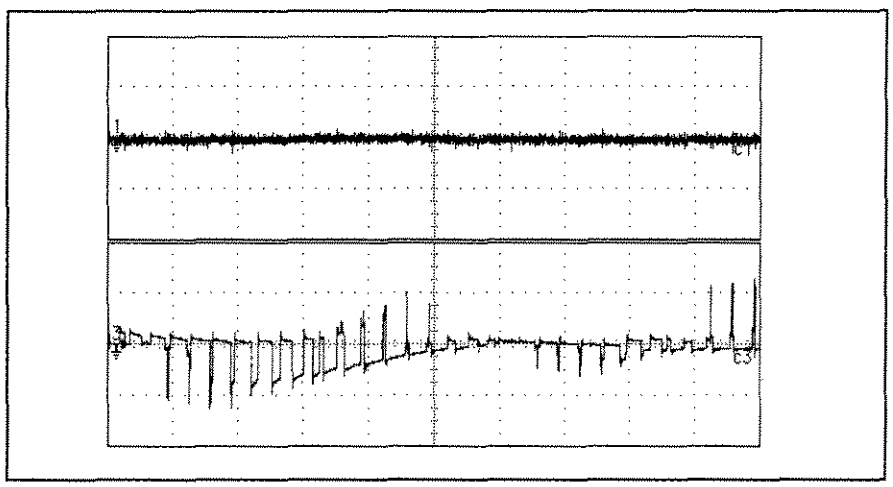

Figure 3. 5 hp, 460 V, Outboard bearing current (negligible) **with ceramic bearings or insulated bearings (200 mA/div), and shaft voltage (4 V/div).**

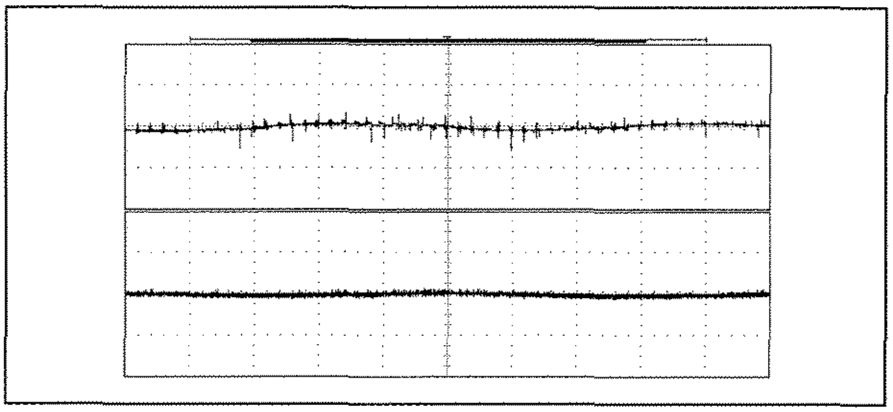

Figure 4. Shaft voltage (top, 4 V/div) and bearing current (bottom, 200 mA/div) with dual-bridge inverter driven motor.

Using Conducting Grease to Provide a Low Impedance Path

Conducting grease provides low impedance paths between the bearing balls and bearing races to eliminate the partial insulating effect. Therefore, the shaft voltage, which is induced from the high-frequency common-mode voltage, is prevented from building up. Unfortunately, a grease with enough conduction contains wearing-conducting elements that can damage the motor bearings.

Building Motors With Faraday Shields

Some motor manufacturers experimented and suggested building motors with a Faraday shield inserted into the air gap. The Faraday shield blocks the electrostatic coupling between the stator and the rotor and thus prevents the build up of shaft voltage. Test results have shown that shaft voltages have been reduced by 98%. However, motors with Faraday shields are not yet commercially available.

Using Specially Designed Inverters

Another solution is to eliminate the problem at the source, i.e., the ASD. This suggests that inverters should be designed so they do not generate common-mode voltages. Some recent works confirm that possible solutions in this direction exist. For example, a space vector control algorithm has been proposed to minimize the magnitude of neutral-to-ground voltage of the motor stator winding to 2 Vdc/3 by synchronizing the switching sequences of the rectifier and the inverter. A dual-bridge inverter (DBI) has also been proposed recently that is designed to generate balanced excitation of the induction motor and therefore does not generate common-mode voltages. Experimental results show that shaft voltages and bearing currents resulting from electrostatic coupling were virtually eliminated (Figure 4).

Final Comments

Bearing current problems are again capturing attention due to the increased number of ASD-related bearing failures. However, the problem can be prevented by taking appropriate measures. Although bearing currents cannot be measured easily without modifications to the motors, shaft voltage waveforms are usually attainable. If the magnitude of a motor's high-frequency shaft voltage is below 3 V, approximately the threshold voltage for the commonly used grease to breakdown, the motor should generally be free of bearing currents. Otherwise, a motor suspected to be working under destructive bearing currents or similarly operated motors have had abnormal bearing failures, one of the presented mitigation techniques should be considered.

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