

Common Mode Chokes or Cores (CMCs) Cannot Prevent Bearing Failure in All Motors

H. William Oh
Electro Static Technology
Mechanic Falls, ME, 04256, USA
William.Oh@est-aegis.com

Abstract –Pulse-width modulated VFD-controlled motors are plagued with by two types of bearing currents:

1) EDM bearing currents, which are generated by motor capacitance; and 2) circulating bearing currents, which are induced only by high-frequency (HF) ground current. Without mitigation, these currents can discharge through motor bearings, damaging them and reducing motor life. But certain forms of mitigation are effective only in protecting against each type of bearing current.

Common mode choke (CMCs) can be used in reducing the circulating bearing currents typically found in large frame motors (greater than 100 HP), but they must be carefully selected and tested to avoid resonance within the motor drive system or saturation of the cores. Since CMCs have no effect on EDM bearing current, when used alone they cannot prevent bearing damage. So even for large motors, CMCs should be used only with other mitigation such as shaft grounding rings or insulated bearings.

I. INTRODUCTION

In recent years, manufacturers of common mode chokes or cores (CMCs) have increased their efforts to market these devices as a means of preventing bearing failures in PWM VFD/inverter-driven motors. CMCs are not new; they have been applied to power electronics for decades. This article will discuss the basic principle of how CMCs work and their effectiveness in mitigating bearing currents.

Today, it is well known that motors driven by VFDs (Variable Frequency Drives) exhibit two types of bearing currents [1-4]: capacitively-coupled bearing current and inductively-coupled bearing current (depending on motor frame size and assuming that the motor frame and the drive frame are well grounded together to avoid any possibility of the rotor ground current [5-6]). In many cases, capacitively-coupled bearing current is referred to as EDM bearing current and inductively-coupled bearing current as circulating bearing current, since these two terms are more descriptive of bearing current damage each causes and how each type of current causes it.

EDM bearing current is generated when a motor itself acts as a capacitor between the rotor and the stator. Circulating bearing current, on the other hand, is induced by high frequency (HF) ground current that flows from the stator to the drive ground point. While small frame size motors (typically below 100 HP) exhibit only EDM bearing currents and negligible circulating currents, large frame size motors (over 100 HP) exhibit both EDM currents and the circulating currents. As motor frame size increases, both EDM bearing currents and the circulating currents increase proportionally.

II EDM BEARING CURRENTS

EDM bearing current is induced by the high dv/dt and capacitances in motors due to the presence of common mode voltage created by a VFD. While more detailed and complete descriptions of this process can be found in other technical papers [7-8], for the sake of simplicity, we have chosen to explain EDM current based on the simple capacitor charging principle to indicate the underlying process.

The charge build-up can be described by the following formula:

$$i = dQ/dt = C \times dV_{com}/dt \quad (1)$$

where, i = current, Q = electric charges, V_{com} = common mode voltage, C = Capacitances within the motor.

As this equation shows (1), EDM bearing current is influenced only by the capacitances of the motor and the dV_{com}/dt of its windings. Here, capacitance (C) is a combination of all parasitic capacitances between windings and the stator as well as the rotor and the stator, etc. If the lubrication of the bearings can withstand them, charges on the rotor surface will build up resulting in a voltage potential between the rotor and the stator. This voltage is not the same as the voltage potential between one end of the shaft and the other end of the shaft. Since the industry does not distinguish between these two definitions of shaft voltage, the voltage potential between the rotor and stator can, therefore, be misunderstood as the voltage potential from one end to the other end of the shaft. The voltage potential between the rotor and the stator can be discharged through bearings when the lubrication film breaks down due to the nature of electrostatic discharges. When the charges discharge through bearings, they produce EDM bearing currents. EDM bearing currents increase proportionally with motor frame size because of the increased surface area which results in increased capacitance. Therefore, EDM bearing currents exist from small motors (below 1 HP) to very large motors (over 1000 HP) and must be mitigated to prevent a premature bearing failure.

III. CIRCULATING BEARING CURRENTS

Typically, as the motor frame size increases to greater than 100 HP, another type of bearing current can occur — circulating bearing currents. These currents circulate from one end of the motor to the other via the rotor, stator, and bearings. Induced by the inductive coupling of ground current, circulating bearing currents have been well researched and analyzed in technical literatures [1, 4, and 9]. In order for the circulating currents to occur, there must be a voltage potential between one end of the motor and the other.

Circulating bearing currents are governed by the inductance of the motor and induced by a circumferential flux, which is excited by high frequency (HF) common mode current [4]. The common

mode current enters the motor via the stator windings and leaves through the grounding connections of the motor to the drive. Detailed analysis of this process can also be found in technical literatures [1, 4, and 9]. Lenz's law states that the voltage potential (ΔV) between one end of the motor to the other end of the motor is governed by the following equation:

$$\Delta V = L \frac{di_{com}}{dt} \quad (2)$$

where, i_{com} is the common mode current, and L is the total inductance of the ground current path through the stator lamination. Therefore, circulating bearing currents can be minimized by reducing the common mode current fluctuations.

Based on this equation (2), the voltage potential that drives circulating bearing current is influenced only by the inductance of the motor and common mode current variations. Circulating bearing current cannot be influenced by common mode voltage, although common mode voltage is indirectly the origin of all bearing currents. Therefore, as long as there is no ΔV , end-to-end shaft voltage, there will be no circulating bearing current, which is evidenced by the fact that only large frame motors (typically over 100 HP) exhibit the circulating bearing currents.

IV. USE OF COMMON MODE CHOKES OR CORES (CMCs)

Several manufacturers of common mode chokes have proposed that these chokes can be used to minimize the bearing currents in VFD-driven motors. Shown below is a diagram of the proposed use of a CMC for this purpose.

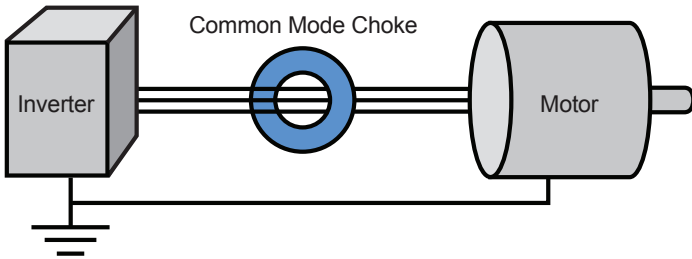


Figure 1. Proposed use of CMC to minimize bearing currents [10]

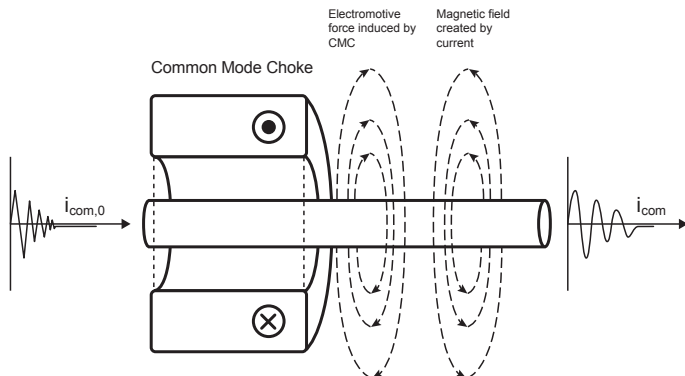


Figure 2. Simplified Diagram of Common Mode Choke Application

Figure 2 shows the effect of a CMC on common mode current.

As can be seen from Figure 2, the HF components of common mode current are attenuated by the CMC based solely on the CMC's inductance and di_{com}/dt since $\Delta V = L_{cmc} \times (di_{com,0}/dt)$ assuming that there is no capacitance coupling between wires. Therefore, the CMC only affects the amplitude of the HF components of common mode current, but has no effect on the common mode voltage or dV/dt . In other words, the use of a CMC only attenuates common mode current and thereby affects circulating bearing current, but has no effect on EDM bearing current. CMCs cannot cancel out common mode current itself; they can merely reduce its amplitude and ripples, i.e., its HF components.

Limitations on the Use of CMCs

Since the PWM waveform of the output signal from a drive contains many frequencies [11,12], the improper selection of CMC for a drive/motor system could result in resonance and could amplify EDM potential in the motor and Ldi/dt voltage amplitudes. The amplitude of HF ground current could also be magnified if the motor and cable system were underdamped [10]. For this reason, system engineers must pay close attention to the proper selection of CMCs when designing drive systems with relatively low power ratings [10].

For un-gapped common mode cores (the majority of feed-through CMCs), several cores must be used in series to obtain the cross-sectional area required to achieve the desired CMC inductance [15]. High common mode current requires a minimum core diameter to avoid saturation. The core diameter should provide a core window area large enough to accommodate the motor cable [15].

Measurement Results

a. Large Frame Motor:

Test results were taken from http://www.magnetec.de/fileadmin/pdf/cb_appl_1.pdf.

Referring to Picture 7 through Picture 9 in the reference, shaft voltages were measured without and with CMC using a large frame motor greater than 100 HP (the authors did not disclose the exact motor frame, but we assume the motor was greater than 100 HP based on the shaft diameter in the picture). As it can be seen in Picture 9, shaft voltage was reduced from 37V to 14V using three CMCs. By shaft voltage, we mean the voltage potential from one end of the motor shaft to the other. The measured shaft voltage, 37V, is a combination of both EDM voltage (associated with EDM bearing current) and end-to-end shaft voltage (associated with the circulating bearing current). When CMCs were applied on the output lines of the drive, the measured shaft voltage dropped by 23 volts to 14V. Assuming that the CMCs reduced the common mode current by 75% based on the Magnetec.de internal report [13], combined with the reduction in shaft voltage of 23 volts, the EDM shaft voltage and the end-to-end shaft voltage can be calculated using Ohms Law of $V=IR$ (assuming no change in resistance of the motor system):

Total End-to-End Shaft Voltage

$$\frac{23}{.75} = 30.7 \text{ volts}$$

- The two components of this 30.7 volts are:
 - o The 75% reduction of common mode current = 23 volts
 - o The 25% common mode current that was unaffected = 7.7 volts

Total EDM Shaft Voltage

The “after” readings of 14V make sense at 6.3 volts of EDM shaft voltage plus the 7.7 volts of remaining end-to-end shaft voltage. These results show that the CMC had no effect on the EDM voltage, leaving the bearings for this motor still subject to EDM bearing discharge damage. Referring to Picture 10 through Picture 12 from the same report, currents from one end of the shaft to a ground point were measured. It is also extremely important to understand the true nature of the measured current in this measurement. Referring to Figure 3, any current generated within the shaft will flow to both the bearings and the wire connected for current measurement as depicted in Figure 3. Therefore, the measured current shown in the reference must have been less than the induced current. If we assume that the induced current of 12A was divided into 7A to the shaft end and 5A to the bearings, there is possibility that the bearing current was still 5A and the shaft end current was 2A after the CMCs were applied.

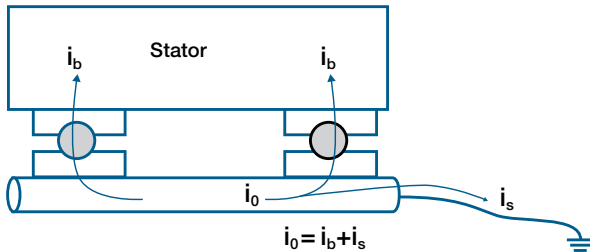


Figure 3. Diagram showing the current flow path on Figure 4. Note that the measured current, “ i_s ” is dependent on the bearing resistance.

Therefore, the measurement of the shaft end current is somewhat meaningless unless the bearings were insulated for the measurement.

b. Small Frame Motor

Referring to Figures 4 and 5, a 10 HP motor with an inverter and CMCs was set up to measure the voltage potential between the shaft and the stator. CMCs reduced the HF ripples but did not reduce the dV/dt and the charge build-up on the rotor via the

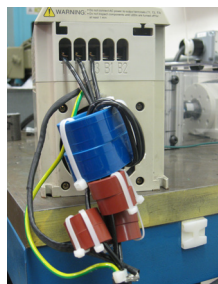
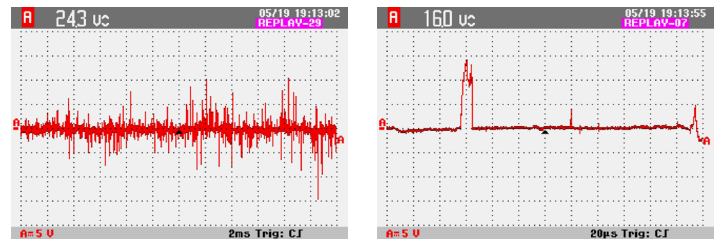


Figure 4. Testing of 10HP motor with CMCs.

Test Results: NO MITIGATION



Test Results: COMMON MODE CHOKE

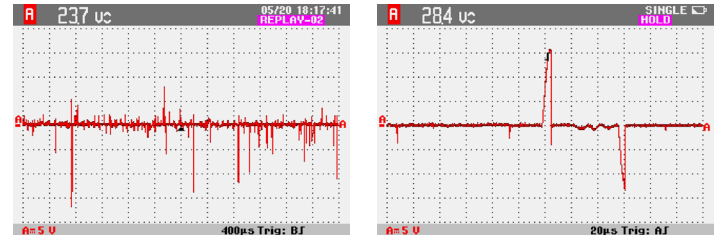


Figure 5. Voltage potential difference between the shaft and the stator without and with CMCs. Please note that the use of CMCs had no impact on the build-up of charges, but ripples were reduced.

motor capacitance. Test results prove the theory that CMCs are only associated with inductance, not the capacitance of the motor. With CMCs installed, the bearing discharge could still be seen from the measurement. Therefore, it is important to understand that CMCs should only be used for large frame motors along with other mitigation techniques such as shaft grounding. Small frame motors up to 100 HP do not need CMCs, because CMCs are not effective in reducing EDM bearing currents.

V. SUMMARY

This article describes the two types of bearing currents that can harm PWM VFD-controlled motors and how each type of bearing current is created. EDM bearing currents are generated by a capacitance effect and circulating bearing currents are induced by an inductance effect. Common mode chokes only reduce ground current, and therefore can only reduce circulating bearing current. In summary,

- PWM VFD-controlled motors are subject to two types of bearing currents: EDM bearing current and circulating bearing current.
- Circulating bearing current is induced only by HF common mode current. For small frame motors, circulating bearing current is negligible. For large frame motors, typically over 100 HP, circulating bearing current must be mitigated.
- CMCs may be used in reducing circulating currents in large frame motors, but careful selection is necessary to avoid a resonance within the motor drive system or saturation of cores based on the motor frame size.
- EDM bearing current is generated only by motor capacitance. The magnitude of EDM bearing current increases as motor frame size increases.
- Even for large motors, CMCs should be used only with other mitigation techniques such as shaft grounding or insulated bearings, since CMCs alone have no effect on EDM bearing current and therefore cannot prevent bearing damage.

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