Overcoming Motor Bearing Failures in AC Motor Drive Systems

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Summary

AC Motor Drive systems utilizing variable frequency controls produce high frequency electrical noise. The noise is superimposed on the power drive lines of the motors in the form of common mode noise. The common mode noise creates a voltage (dv/dt) across the rotor/stator of the motor resulting in a discharge current through the motor bearings to the motor raceway. This current discharge produces an EDM effect (Electrical Discharge Machining) that causes destructive pitting and damage to the motor raceway. The end result is premature failure of the motor causing expensive repairs and system downtime. This paper discusses the three best solutions to avoid motor failure in this circumstance.

History

All rotating machines develop motor bearing currents and problems that cause premature failure. This has been well understood since 1924. With Sinusoid driven motors, the currents originated from high values of electro-magnet induced rotor shaft voltages caused by magnetic dissymmetries inherent in the motor construction.

The Variable Frequency Drive (VFD) was created approximately 30 years ago to provide substantial energy savings and precise control in commercial and industrial applications. Necessary changes from traditional markets of fossil fuel have led to markets for alternative power generation as well. All of these markets have benefitted from VFD's.

Advantages of VFD's

1) Fast switching
2) Speed variation
3) Heavy load inertia starting
4) High starting torque requirements
5) Low starting current requirements
6) High efficiency at low speed
7) High power factor

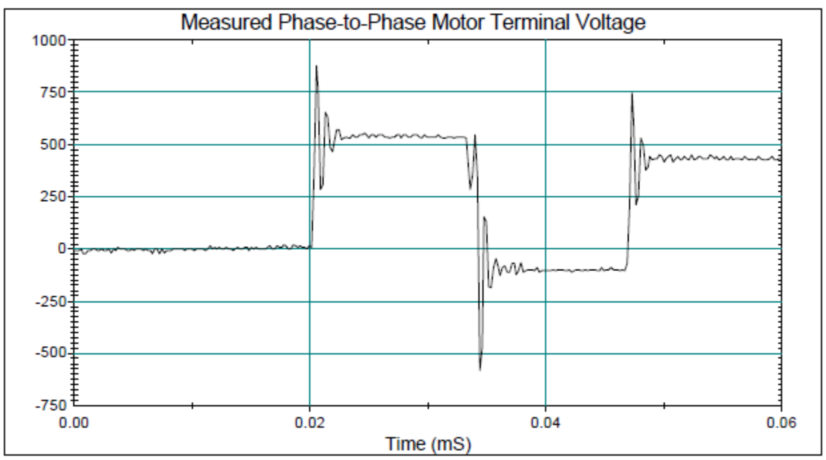
With every new industry solution, new issues are created. VFD systems are not sinusoidal but are a continuous generation of pulses (Pulse Width Modulation or PWM). The pulses have a constant voltage and a dv/dt rise and fall time of the pulse. The original VFD systems were based on Bipolar Junction Transistors. The trend now is toward IGBT systems which give a faster switching dv/dt with lower switching losses and a more efficient drive. But

IGBT systems also create new problems associated with the system performance. The IGBT introduces parasitic currents in the form of two potential destructive characteristics:

a. Transient Voltage/ Harmonic Distortion/Reflective Waves
b. Higher magnitudes of electrical ground noise current

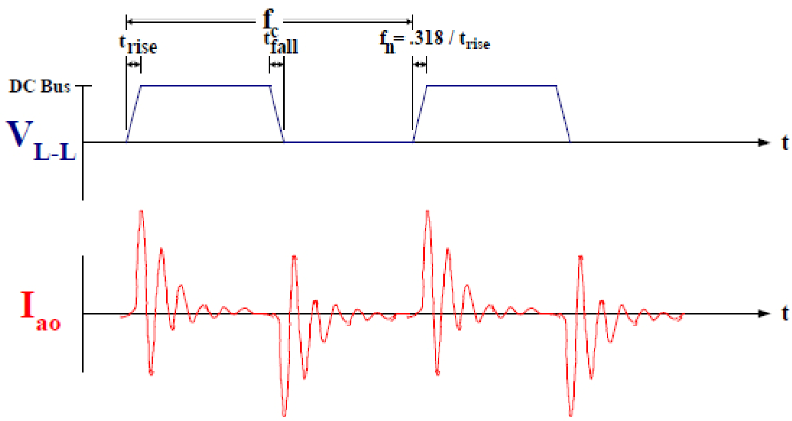
Transient Voltage

Each pulse in a PWM system is not a clean square pulse. Each Rise and Fall of the pulse has an over shoot or transient over-voltage. This over-voltage phenomenon is also known as "Reflected Wave", "Transmission Line Effect" or "Standing Wave". The per unit overvoltage magnitude (motor *Vll(pk)* / drive *Vbus*) is dependent upon drive-cable-motor circuit dynamics defined by drive output voltage magnitude and rise time, cable surge impedance characteristics, motor surge impedance to the pulse voltage, cable length and spacing of the train of pulses by the PWM modulator.



Common Mode Noise

Both BJT and IGBT generate abrupt voltage transitions on the motor drive output. These are an inherent source of radiated and conducted noise. The majority of drive related noise interference with PLC's, controllers and instrumentation is conducted noise currents whose magnitude is determined by the amount of stray capacitive coupling phase to ground during the fast switching voltage transitions on the drive output. IGBT output dv/dt is 10 to 40 times greater than the BJT. Both the cable and the motor line to ground capacitance interact during the high dv/dt transition and generate ground currents. This is the common mode ground current.



Noise Source: Drive Induced Common Mode Current

Radio Frequency Interference

The IGBT inverter system is generating not only radio frequency interference along the motor cables but there is also the Electromagnetic Interference (EMI) being radiated into the air in frequency range of 1.7MHz to 30MHz. The emanating interference can have devastating effects on unprotected signal circuits. As an example, it has been documented that IGBT generated EMI causes interference with radio controlled cranes in a building, making the cranes operate intermittently. Proper shielding of the motor cable and signal cables can help attenuate the effects, however the addition of the inductor absorbers can eliminate the interference at the source.

Electrical Discharge Effects on Motor Bearings

It has been well documented in many papers and presentations about the affects of dv/dt voltage spikes and common mode noise in VFD motor control and operation. All rotating machines develop bearing currents, whether DC or AC, high or low horsepower. The shaft voltage induced along the axial length of the machine has a resulting circulating motor bearing current whose magnitude is limited only by the motor bearing impedance. Motor Bearing impedance is low (like a resistor) at low speeds and attains values in the meg-ohm range (like a capacitor) as motor speed increases above 10% of rated. Technical literature indicates that as speed increases, the balls/rollers ride on a lubricating oil film forming a boundary between the ball bearing and the raceway, with the exception of instantaneous asperity point contacts. The oil film acts as a capacitor that gets charged by rotor shaft voltage. When the shaft voltage applied to the oil film capacitor reaches the dielectric breakdown strength voltage or when a ball bearing asperity point contacts the raceway in a small contact area, then a destructive instantaneous high discharge current (EDM) of the film capacitor takes place, pitting the bearing. The amount of mechanical damage depends on the magnitude of bearing current density defined as bearing current divided by bearing contact area. To shorten this, the shaft voltages find a ground path through the bearings, destroying the lubrication and bearings in the motor, and/or causing interference in tachometers or sensors. The premature failure of the bearings and/or sensors results in downtime of the manufacturing process and ultimately a loss of revenue.

Electrical Discharge Effects on Electronics

The generation of transient voltages and common mode currents not only affects the motor bearings. Left unchecked, the noise also affects any instrumentation connected to the drive-cable-motor system such as tachometers and temperature sensors. In many cases there are signal lines running from process and programmable controllers to the motor system design to automatically control the on/off state and speed of the motor system. These can all be affected by transient voltages and common mode currents.

Determination of a Potential Problem

The Electrical Discharge is a charged discharge similar to a spark. A large current is flowing from a high potential to ground. This spark or arc generates a high frequency noise that can be detected. A test instrument with antennae can sense every time the spark is generated. One such piece of test equipment is the SKF EDD test equipment, model TKED 1. Holding the TKED 1 close to the motor where the motor bearings are located, the equipment measures every discharge. This is a very safe method of identifying potential problems in that there is no contact with the motor.

Solutions

There are three solutions that are commonly employed to solve or correct the effects of power line noise on EFD motor systems:

1. Shaft Grounding Device
2. Insulated Bearings
3. Inductive Absorption Device

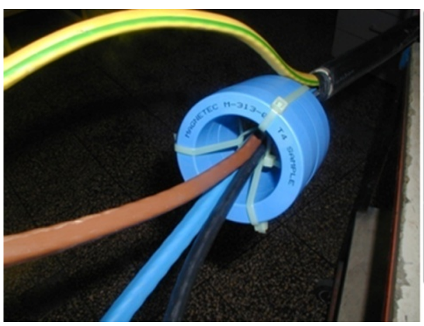
Shaft Grounding Device – This is a mechanical solution where devices have a brush or fiber, usually copper or other high conductivity metal that rides on the motor shaft. Current does not go through the bearing but is instead conducted directly to ground through the brush. These brushes are especially selected to tolerate misalignment and maintain rotating contact throughout the brush's life when properly maintained. There are potential problems with this solution.

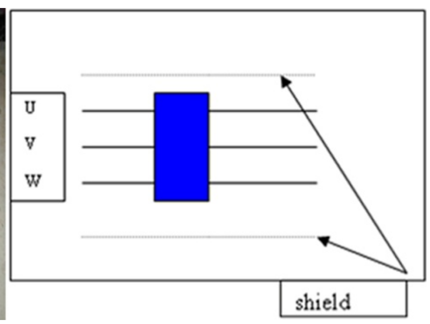
1. Brushes must be properly maintained/replaced – System becomes expensive over time
2. Brushes lose contact with the shaft over time due to heat, contaminants and physical wear
3. Must be replaced periodically causing downtime for maintenance
4. This solution only protects the motor bearings

Insulated Bearings – This is a mechanical solution where the motor bearings are made of an insulated material or insulated coating. This system is effective at avoiding damage to the bearings and the resulting downtime of the motor system. The problem with this solution is:

1. Very expensive
2. Motor bearings do have to be replaced, increasing the expense
3. This solution only protects the motor bearings

Inductive Absorption Device – This is an electrical solution where inductive components are placed over the drive cables to absorb the transient voltage and common mode currents. The Inductive components need to have high permeability, high saturation and low power loss. They do not affect the symmetrical power currents but efficiently dampen the asymmetrical EMI noise currents. This creates a common mode choke. The initial installation cost is about the same as other solutions. The long term costs are negligible as there is practically no maintenance needed with this solution.



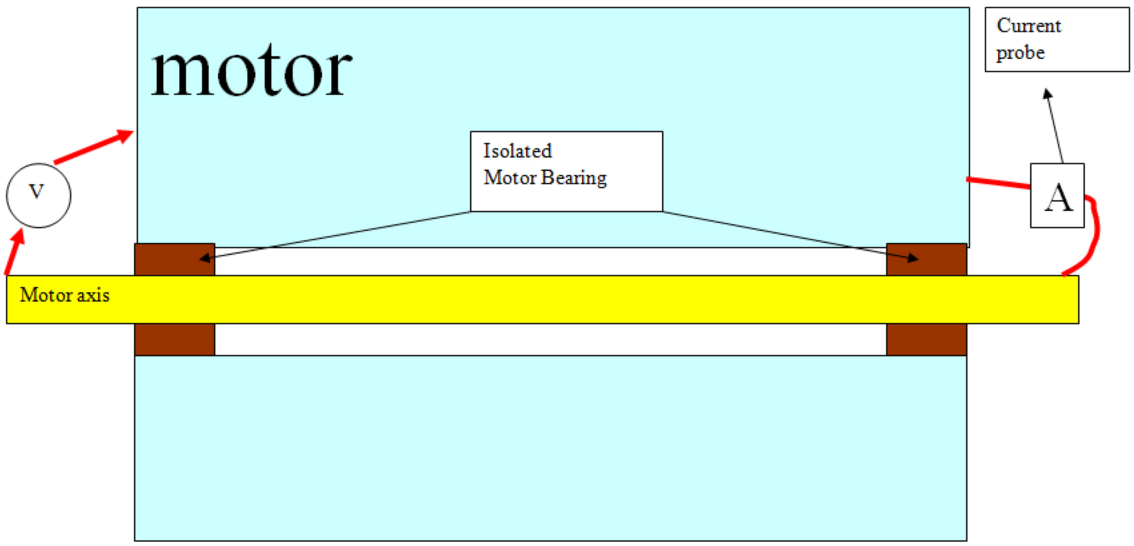


The advantages of the Common Mode Choke solution are:

1. Installation cost same as other solutions
2. Reduces line noise by a factor of 4:1 or better
3. Can be retrofitted with little or no problem
4. Reduces transient voltages and common mode currents before they reach the motor system.
5. Electronic devices are protected as well as the motor bearings
6. Lifelong solution – magnetic properties do not degrade over time nor affected by heat

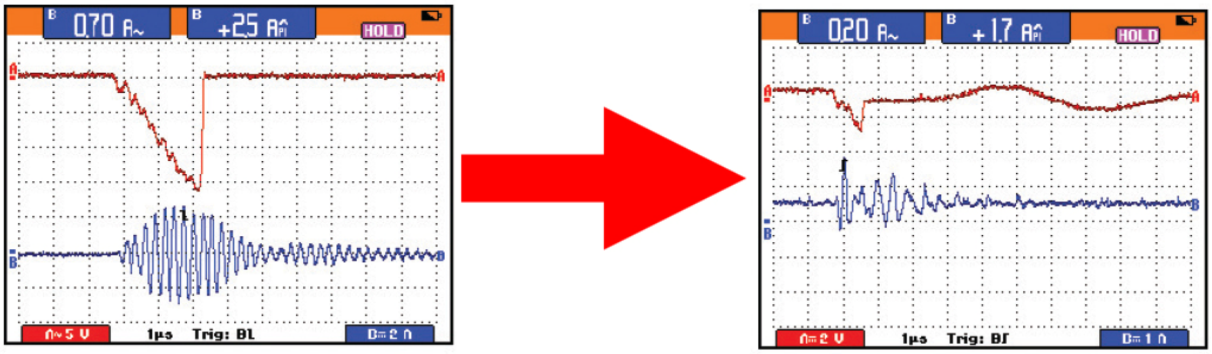
Toroids made of **Nanocrystalline** magnetic material meet the requirements for magnetic absorbers. These toroids in high permeability and high saturation are placed over the drive cables (U-V-W). Manufacturers produce cores in **Nanocrystalline** material designed and manufactured specifically for this application. Typical cores are made with a 30,000 permeability and offer a high saturation of 1.2T and low power loss. Using cores with such high permeability allows the use of only a few cores in a one turn configuration to achieve a high inductance and high impedance needed to filter the parasitic drive currents going to the motor. Below is a typical example of motor protection on a 250KW system in the paper processing industry.

Shaft Voltage and Bearing Current Measurements are taken from the Axis to the ground, which in this case is the motor casing. A simple method is shorting the motor casing to the axis (copper brush attached to the axis end of the shorting wire) and placing a current probe over this shorting wire.



As an active example, a typical 150hp IGBT/motor system was chosen for testing. The motor cables were shielded and about 100 ft long. Measurements were taken before and after the addition of the Nanocrystalline cores. Ten Nanocrystalline cores were placed over the three leads at the output of the inverter inside the shielding. Results show 10:1 reduction in the parasitic bearing currents damaging the motor bearings and a 3:1 reduction in the p-p Shaft voltage readings. Also of interest is the reduction in the noise levels in the ground current. Both power ground and signal ground share the same common ground. When noise levels on the ground current are high enough, the noise is injected into signal circuits inductively coupled to the common ground. The ground loop current caused by the noise also generates a radio frequency noise that again affects surrounding equipment primarily on the signal lines.

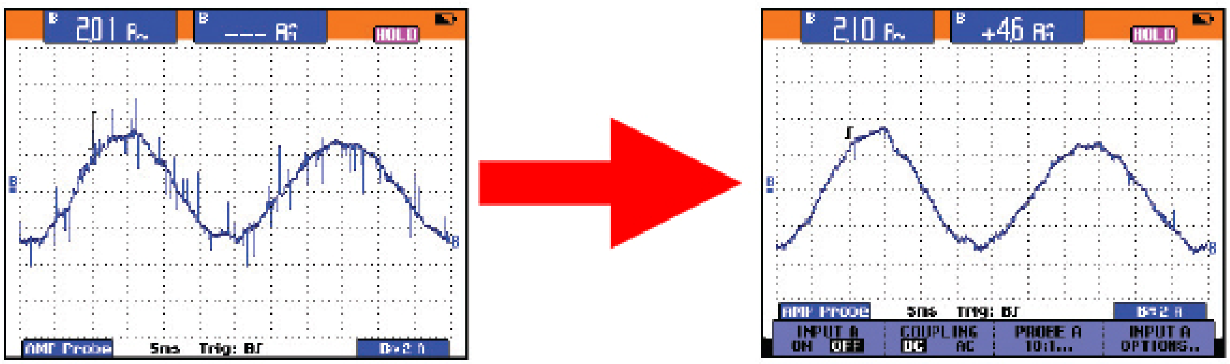
Shaft Voltage and Bear Current Wave Forms



Before Inductive Absorber

After Inductive Absorber

Ground Current Wave Forms



Before Inductive Absorber

After Inductive Absorber

The **Nanocrystalline** Solution

In the given configuration **Nanocrystalline** soft magnetic cores work as a single turn common mode suppression choke. **Nanocrystalline** absorbers are superior to other soft magnetic materials because of significant advantages concerning their magnetic properties; very high permeability, high saturation of low power loss. Ferrite inductive absorbing material is limited to a practical permeability of 10,000. Nanocrystalline is typically 30,000 for this type of application and can be processed to achieve higher permeabilities in the range of 60,000 – 90,000. Ferrite is a saturation point of around 400mT at elevated temperature while Nanocrystalline runs 1200mT at the same temperatures. As a consequence only about 20% of 'magnetic mass' is required – i.e. a significantly reduced number of cores is suitable.

Nanocrystalline Cores come in many sizes, both round and oval, to fit all configurations. Here is a list of the standard **Nanocrystalline** cores available. Custom sizes are also available.

Core Dim.	Finished Dim.	l_{fe}	a_{fe}	Al @ 10kHz	I_{sat}*
OD x ID x Ht	**OD x ID x Ht**	**[cm]**	**[cm^2]**	**[µH]**	**[Apeak]**
[mm]	**[mm]**				
63 x 50 x 30	68 x 43 x 36	17.7	1.44	23.3 - 46.6	3
63 x 50 x 30	OVAL	17.7	1.44	23.3 - 46.6	3
80 x 63 x 30	85 x 57 x 35.5	22.4	1.86	24.1 - 48.2	4
80 x 63 x 30	OVAL	22.4	1.86	24.1 - 48.2	4
100 x 80 x 30	105 x 75 x 35	28.2	2.25	22.5 - 45.0	5
100 x 80 x 30	OVAL	28.2	2.25	22.5 - 45.0	5
130 x 100 x 30	135 x 94 x 34	35.9	3.33	24.6 - 52.9	6.5
160 x 130 x 30	165 x 123 x 34	45.4	3.24	20.9 - 45.0	8.5
160 x 130 x 30	OVAL	44.7	3.3	20.9 - 45.0	8.5
200 x 175 x 30	208 x 166 x 37	58.8	2.74	12.3 - 24.6	11
236.5 x 201 x 30	OVAL	69.6	3.94	14.5 - 29.9	13
300 x 254 x 30	304 x 246 x 38.7	87.1	5.2	15.8 - 31.5	16.5
300 x 254 x 30	OVAL	87.1	5.2	15.8 - 31.5	16.5
* "Saturation Current" (Peak value) @ B = 100 T / $\mu_{max} = \mu_{nom}$ x 1.4 / N = 1					

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