FAN ENGINEERING

Information and Recommendations for the Engineer FE-4000

Variable Frequency Drive (VFD) Induced AC Motor Shaft Current and Bearing Damage

Introduction

Currently the most popular method of controlling the speed of an AC fan motor is through the use of a variable frequency drive or VFD. If the system performance follows fan laws, controlling the speed of a fan is a more efficient method of controlling air flow than the use of vanes or dampers. One disadvantage that VFD's have, however, is the potential to induce destructive current through the motor shaft, bearings and motor housing. Induced voltage in the shaft can reach levels that cause the dielectric resistance of the motor bearing oil or grease film separating internal bearing components to be exceeded. This voltage potential will then discharge to ground through the bearing in a brief arc between the bearing ball or roller and raceways. These arcs leave small EDM (electrical discharge machining) pits in the raceways and balls or rollers of the bearing. Over time, damage to the bearing can accumulate until bearing failure occurs. It should be noted, however, that damaging shaft currents are not present on all motors running on VFD's. There are many motors running on VFD's without issues in installations where there are no mitigation measures in place. The occurrence of bearing damage due to shaft current is somewhat random and difficult to predict.

VFD Induced Shaft Current

VFD's operate on the following principles:

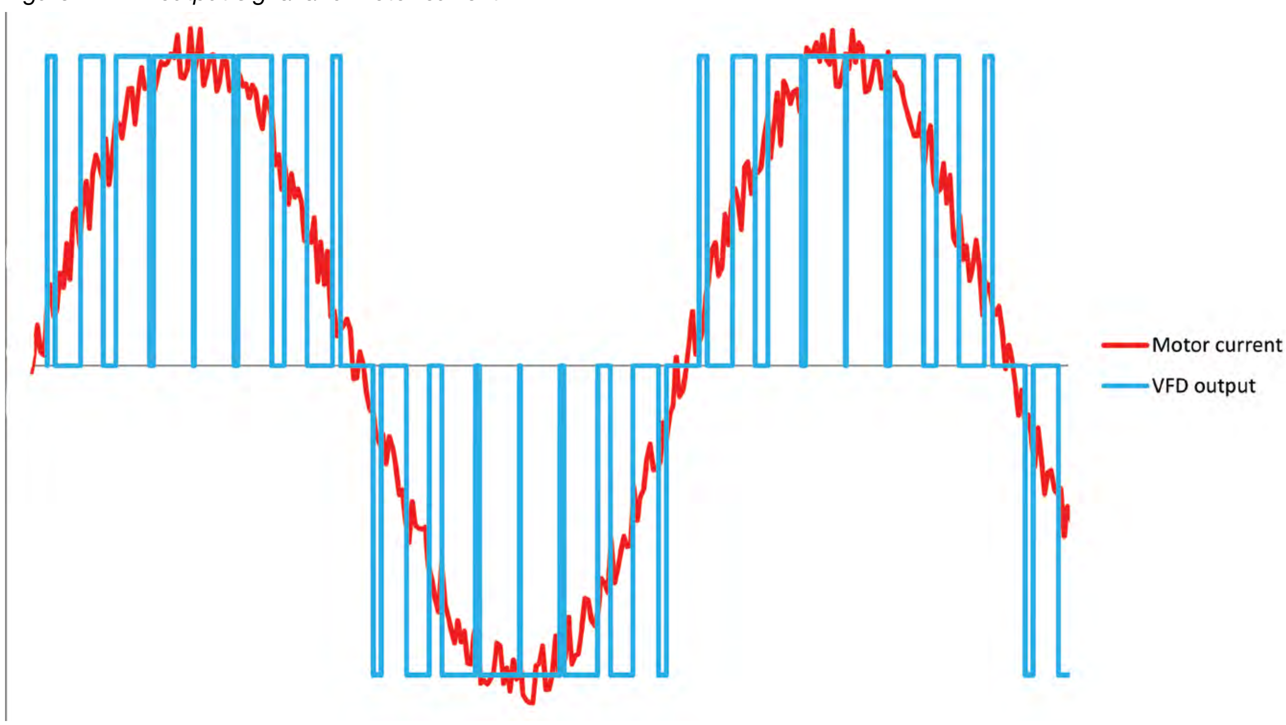
- The AC voltage signal is converted to DC voltage.
- IGBT's (insulated gate bipolar transistors) provide high-frequency switching.
- DC voltage is converted into a pseudo AC signal with variable frequency by voltage inversion and pulse width modulation (see Figure 1).

The frequency of the electrical pulses generating this signal is in the range of 1 to 20 kHz.

Voltage potential at the motor shaft is induced due to the following:

- Electric capacitance:
  - o Between the motor winding and housing,
  - o Between the winding and the rotor
  - o Between the rotor and the housing
  - o In the bearings.
- These capacitances are charged and discharged with every voltage pulse of the VFD.
- This sets up a high frequency current leakage from the winding to the housing and then to ground.
- The current leakage sets up a magnetic imbalance in the motor which induces a high frequency shaft voltage.

Figure 1. VFD output signal and motor current.



Initially the lubricating film of oil or grease in the bearings acts as an insulator preventing the flow of electric current. If the shaft voltage reaches a sufficient magnitude (around 20-30 volts), the dielectric resistance of the oil or grease film separating the bearing components will break down. The rotor to housing capacitance will be discharged through the bearing in a brief, high amperage arc. The relationship between the winding to housing capacitance, the winding to rotor capacitance and the rotor to housing capacitance can cause a circular current to set up. When this happens, current will flow from the rotor to the housing through the non-drive-end bearing and back to the rotor through the drive-end bearing. This current is driven primarily by the capacitance between the winding and housing. This capacitance increases in proportion to the shaft height. Additional voltage spikes due to the capacitance of the power cable between the VFD and the motor and the high switching frequency of the VFD are superimposed on the motor voltage. These superimposed voltage spikes increase in proportion to the cable length. Induced AC voltage amplitudes of 60 volts or greater have been observed in motors with VFDs.

Bearing Damage

In cases where induced shaft voltage exceeds the dielectric resistance of the bearing lubrication film, electric current will arc from the bearing ball or roller and raceway with sufficient amperage to create EDM pit. Due to the high frequency of the switching circuits, the electrical discharge arcs through the bearings can also occur at a high frequency. Even after a short period of time, the entire bearing race will become coated with small EDM pits. The inside surface of the bearing race will take on a “frosted” appearance. Eventually the bearing race will become severely pitted and fluted. Excessive noise and eventual bearing failure are the end results. Motor bearing failures have been documented after as little as a few months of operation. The majority of motor bearings that experience this issue will fail after 3 to 12 months of operation.

Figure 2. Bearing race exhibiting a "frosted" appearance.

Figure 3. Bearing race exhibiting "fluting".

Prevention

Due to the number and complexity of potential causes, the occurrence of bearing damage due to shaft current is difficult to predict. However, the likelihood of damage can be greatly reduced by addressing the predominant causes. Prevention is particularly prudent when the cost of replacing motor bearings is very high and when the motor is a component in a critical process. The goal of any preventative measure is to reduce shaft voltage to a level that is not damaging to the bearings. Steps can be taken to prevent bearing damage due to shaft current including:

- Proper grounding and bonding of all components in the system.
- Insulated bearings, especially the non-drive end bearing.
- Avoiding very long cable lengths (> 1000 ft) between the VFD and motor.
- Use of a VFD with IGBT pulses with switching time > 1μs.
- Use of a voltage filter at the VFD output.
- Use of a shaft grounding ring.

Proper grounding and bonding is necessary to ensure all the components in the system are at exactly the same electrical potential. In this way, the neutral voltage potential between the various components is minimized in order to reduce current leakage.

Insulating the motor bearings increases the resistance of the bearings current flow from the shaft. Normally an insulating sleeve or coating is placed between the outer ring and bearing housing. This is especially important for large motors (NEMA frame sizes 404T or greater / motor hp > 100) where circular shaft currents may develop. Insulation of the non-drive-end bearing is preferred for preventing circular shaft current due to the fact that the circular current will flow from the shaft through the non-drive end bearing to the housing and back to the shaft through the drive-end bearing. Insulation of the non-drive end bearing breaks this current path. If only the drive-end bearing is insulated, circular current may still occur through the coupling and driven equipment shaft and bearings. Insulation of the non-drive-end bearing is common practice among motor manufacturers.

Figure 4. Motor Bearing with an Insulated Sleeve.

The capacitance of the motor cables combined with the high rate-of-rise of the high frequency voltage pulses can induce additional voltage spikes on the rotor of an AC motor. The capacitance of the motor cables increases proportionally as length increases. These superimposed voltage spikes can exacerbate the problem of induced shaft current. It is generally advisable to minimize the length of the cabling between the VFD and the motor. The recommendations of the VFD supplier with respect to appropriate cable type and length should be followed.

The current driven by the cable capacitance is proportional the voltage rate-of-rise of the VFD signal according to:

$$I_c = C_{cable} \cdot \frac{dV}{dt}$$

The current amplitude can be reduced by selecting a VFD with a slower voltage rate-of-rise.

Sometimes fans must be installed in existing facilities where poor grounding or long cable lengths are unavoidable. In such cases, it may be wise to consider installing a signal conditioning voltage filter to prevent voltage spikes induced by the capacitance of the cable or from other sources from impacting the motor.

Additional protection of the motor and driven equipment bearings again shaft current can be achieved by connecting the shaft directly to ground through a shaft grounding brush or ring. Also, in the case of an arrangement 4 fan (fan wheel mounted directly to the motor shaft), shaft grounding protects the motor against static electricity generated by the fan wheel. Grounding brushes have been proven to be effective, but require maintenance and are prone to failure due to wear. More recently, the shaft grounding ring (SGR) has been developed. The shaft grounding ring contains conductive microfibers that provide more points for conduction and are more durable than conventional brush fibers. A shaft grounding kit utilizing a shaft grounding ring can be installed to the motor shaft, grounding the motor shaft to the frame. Some AC motors may be purchased with shaft grounding rings pre-installed. In order for the shaft grounding ring to function effectively, the shaft must be cleaned before installation in order to ensure proper conductivity between the shaft and the grounding ring. Also, the motor must not be idle for an extended period of time as this may allow rust to build up on the shaft, causing the grounding ring to be ineffective. Internal installation is available on some motors, providing a cleaner environment and protection from damage for the shaft grounding ring. If the shaft is clean and free of rust, the combination of a shaft grounding ring and an insulated non-drive-end bearing provides excellent protection against EDM damage to bearings.

Figure 5. Externally mounting shaft grounding ring.

Figure 6. Motor with internally installed shaft grounding ring.

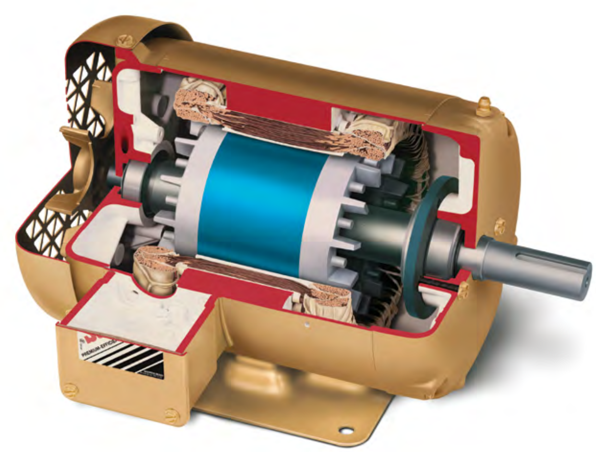


Table 1. Shaft Current Prevention Recommendations

Situation	Recommendation
All VFD applications	Minimize VFD frequency and voltage rate-of-rise
	Use shortest possible cable lengths
	Proper cable shielding
	Proper equipment bonding and grounding
Motor frame size > NEMA 404T	Insulated non-drive end bearing
Facility with poor grounding or long cable length	Signal conditioning voltage filter and/or shaft grounding ring
Large expensive motor and/or critical processes	Insulated motor bearings and shaft grounding ring

Conclusions

VFDs are an economical and popular choice for controlling the speed of fan drive AC motors. Bearing damage can result from induced shaft current caused by the VFD voltage switching. The occurrence of damaging levels of shaft current can be minimized by proper grounding and bonding and minimizing motor cable lengths. Selection of a VFD with a slower voltage rate-of-rise will also reduce induced current. Insulation of the non-drive-end bearing in the motor prevents circular shaft current from occurring by increasing the resistance of the circuit to current flow. Under less than ideal installation circumstances such as poor grounding or long cable lengths, a signal conditioning voltage filter at the VFD output can be used to eliminate voltage spikes from reaching the motor. An additional level of protection against damaging current through the motor bearings is to install a shaft grounding ring. The countermeasures described above should be evaluated based on cost, installation conditions and the recommendations of the VFD and motor suppliers.

AEROVENT
INDUSTRIAL VENTILATION SYSTEMS

WWW.AEROVENT.COM

5959 Trenton Lane N. | Minneapolis, MN 55442 | Phone: 763-551-7500 | Fax: 763-551-7501