Bearing currents

The five key aspects

1. Bearing currents are generated by the use of variable-frequency drive (VFD) in electric motor driven systems and can lead to premature bearing failure.
2. Bearing currents and preventive measures must be factored into the planning of electric motor driven systems with an VFD.
3. There are three types of bearing currents:
   - Discharge bearing currents
   - Circulating bearing currents
   - Rotor ground currents
4. Possible means of avoiding bearing currents:
   - In general: good, high-frequency earthing
   - Symmetrical, shielded motor cables (three-phase) hinder rotor ground currents.
   - Use of special bearings (hybrid, ceramic and insulated bearings)
   - Use of shaft grounding brushes, common mode chokes or filters
5. Bearing currents can be detected indirectly, but direct measurement is not possible.

Context

Using variable-frequency drive (VFD) can reduce the energy consumption of electric motor driven systems in many cases. Accordingly, VFDs are frequently installed nowadays in electric motor driven systems with variable loads. However, the use of VFDs can generate undesirable bearing currents in electric motors that can lead to bearing damage and premature failure.

Introduction

It has long been known that bearing currents in electric motors can cause premature failure. Basically, there are three different categories of bearing currents:

1. Bearing currents generated by a motor's asymmetric magnetic fields.
2. Bearing currents generated by a motor's driven load (e.g. via the electrostatic charging of the driven machine).
3. Bearing currents generated by the use of VFDs.

The first two categories have already been extensively researched, and there are various means of preventing such bearing currents. Consequently, this Fact sheet will focus exclusively on bearing currents generated by the use of VFDs with voltage link.

Damage caused by bearing currents

In an electric motor, bearing currents are always caused by a voltage across the rotor bearing (bearing voltage). From an electrical perspective, the bearing acts like a capacitator in normal motor operation, with the oil film building a dielectric. If the voltage across the bearing is too high, a electric discharge takes place in the bearing, as a result of which very high local currents can flow through the bearing (bearing current).

If the current density (current per surface unit) is high enough, metal in the bearing ring can melt or even be vaporized. Extensive micropitting occurs. After a while, the bearing ring shows a typical grey trace or even ripples. Lubricant can also be impacted by bearing currents. Both can lead to premature failure of bearings.

Figure 1: The two typical damage patterns caused by bearing currents; on the left: grey trace, on the right: ripple formation.

Fundamentals

Common mode voltage

The occurrence of bearing currents caused by VFDs is always due to the common mode voltage.

During mains operation, the sum of the three phase to neutral voltages at the motor is always zero. With a conventional VFD, however, this is no longer the case, because in an VFD with a voltage link, only discrete voltages and switching states are available. Figure 3 shows the time course of a common mode voltage for a two-stage VFD over one mains period.

This common mode voltage concerns the motor's parasitic capacities and is the source of the bearing currents. Both the level of the common mode voltage and the slope of the voltage change can impact the bearing currents at the same time.

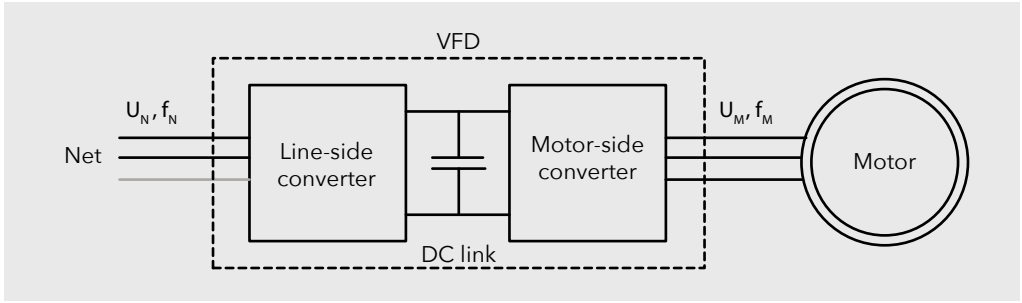

Figure 2: Variable-frequency drive (VFD) with voltage link and motor (Fact sheet No. 25) with phase voltages

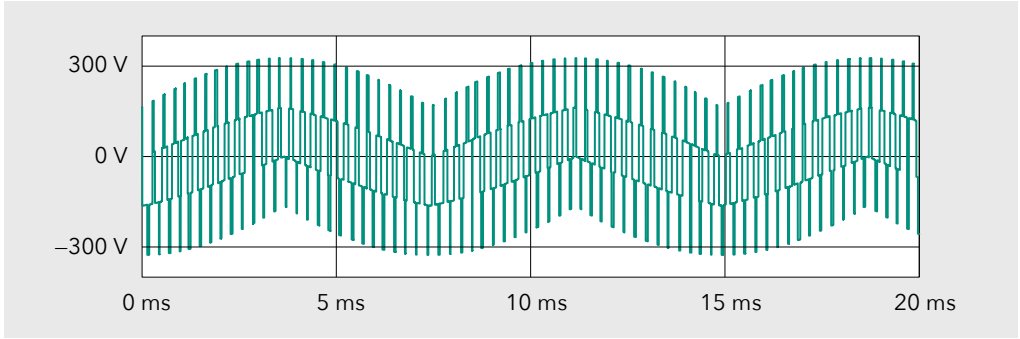

Figure 3: Time course of the common mode voltage over a mains period.

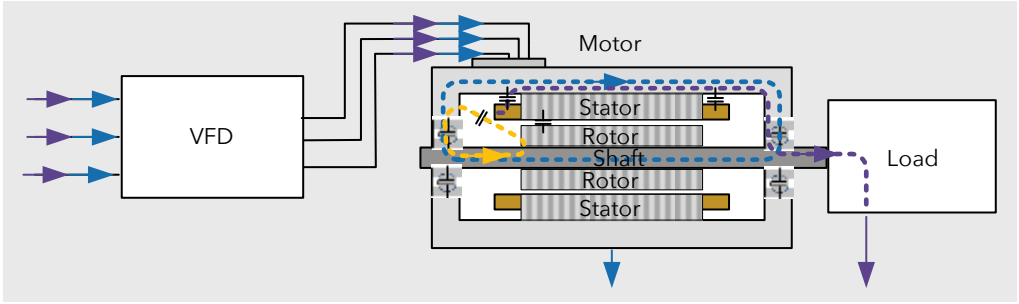

Figure 4: Bearing current paths. Yellow: Discharge bearing currents. Blue: Circulating bearing currents. Purple: Rotor ground currents

Bearing currents caused by VFDs

The bearing currents generated by the common mode voltage can be divided into different types (Figure 4). This distinction is important, because the countermeasures differ for each category. The following three types of bearing currents can be problematic:

- Discharge bearing currents (yellow)
- Circulating bearing currents (blue)
- Rotor ground currents (violet)

Discharge bearing currents

The common mode voltage is conducted to earth via various capacitators. Depending on the voltage divider, part of the common mode voltage also drops across the bearing. For common motors, the bearing voltage corresponds to approximately 5% of the common mode voltage and is thus determined by the level of the push-pull voltage. In the event of electrical discharges in the bearing, the energy stored in the parasitic capacities is converted in the bearing. However, given that small motors have small bearings, current density and hence the harmfulness of the discharge bearing currents are generally significantly increased in small motors.

Circulating bearing currents

The VFD's power supply creates a circular magnetic flux around the shaft, which changes at high frequency. This leads to tension between the shaft ends, and opposing tensions form around the two bearings. For a given electric motor driven system, the magnitude of the bearing currents is thus determined by the slope of the voltage change. With small motors, the shafts are normally so short that these bearing currents are relatively small and no damaging bearing currents occur.

Rotor ground currents

If the motor frame is not properly earthed, an additional hazard arises. If the impedance to earth via the shaft and the driven machine is significantly smaller than via the earthing conductor to the motor frame, part of the common mode current flows away from the frame as rotor ground current via the path «motor bearing – coupling – bearing of the load», thereby damaging the bearings. This type of bearing current can occur in motors of any size. For a given electric motor driven system, the magnitude of the bearing currents is determined by the slope of the voltage change.

Roughly generalized, the above statements can be summarized as follows:

- **Discharge currents** can occur with all motor sizes. However, they are mainly harmful in small- to medium-sized motors (up to approx. 75 kW).
- **Circulating bearing currents** mainly occur in medium- to large-sized motors (from approx. 10 kW).
- **Rotor ground currents** can always occur if the motor is earthed via the load and the motor frame is not properly earthed. If shielded cables with good connections to the VFD and motor side are used, there should not be any rotor ground currents.

Measurement

A great many factors determine whether bearing currents occur, what type of bearing current occurs and whether the bearing currents are harmful. Consequently, onsite measurement is sometimes essential to determine whether bearing currents are present. Bearing currents cannot be measured directly, but they can be recorded indirectly in various ways.

Vibration measurement

Vibrations and noises are often the first indications that harmful bearing currents are occurring. Vibration sensors and sophisticated evaluations can detect bearing damage relatively early. However, bearing currents are only detected in this way when damage already exists.

Measurement of voltage between shaft and frame

The voltage between shaft and frame corresponds to the voltage across the bearing. Brushes can be used to measure this voltage, which is a good way to detect bearing currents. The course of the voltage across the bearing corresponds to the course of the common mode voltage without bearing currents, whereby the bearing voltage is approximately 20 times lower than the common mode voltage for common motors.

If discharge bearing currents occur, the bearing voltage collapses some time after the voltage change. A sudden drop in bearing voltage thus indicates discharge bearing currents (Figure 5).

With circulating bearing currents and rotor ground currents, the electrical discharge in the bearing occurs directly during the switching process. However, the bearing voltage does not drop back to zero, as a current continues to circulate through the bearing or in the motor after the discharge. The high voltage before the discharge is only present for a relatively short time. Therefore, depending on the oscilloscope setting, the bearing voltage may only appear to take on small values despite bearing currents. However, the shape of the bearing voltage clearly indicates bearing currents.

The disadvantage of this voltage measurement is that the shaft must be accessible. Due to the relatively fast voltage changes, care must also be taken to ensure that a suitable oscilloscope is used.

Figure 6 clearly shows once again that the effective value of the bearing voltage alone does not allow any conclusions to be drawn regarding bearing currents. Measurements with multimeters are therefore inadmissible, and only the time course of the bearing voltage shows whether bearing currents occur.

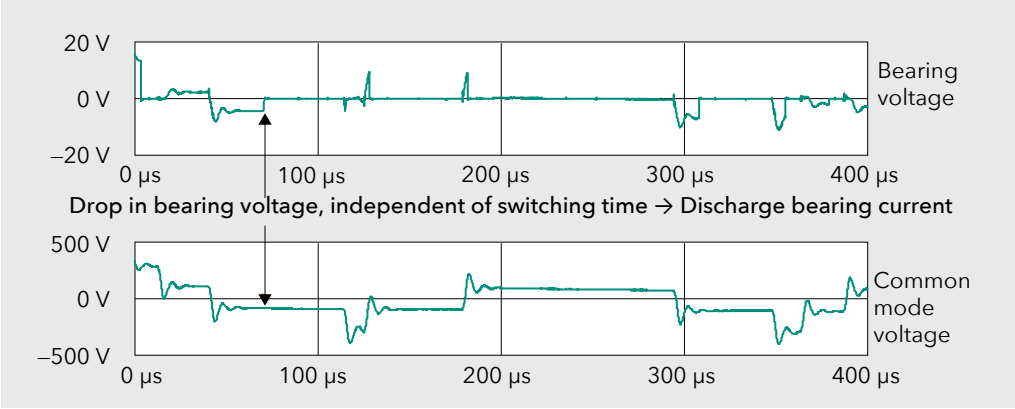

Figure 5: Course of the bearing voltage (top) and the common mode voltage (bottom) when discharge bearing currents occur.

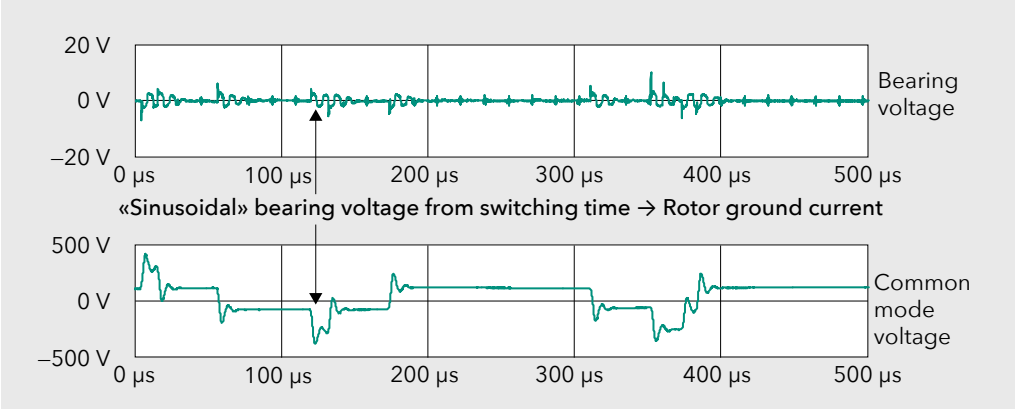

Figure 6: Course of the bearing voltage (top) and the common mode voltage (bottom) when rotor ground currents occur.

Measurement of the common mode current

The common mode current is often measured to detect bearing currents.

Discharge bearing currents are a discharge in the motor. However, this discharge current is not visible as a common mode current. Therefore, no conclusions can be drawn as to the presence of discharge bearing currents by measuring the common mode current.

Circulating bearing currents and rotor ground currents are, however, proportionally visible in the common mode current. Yet since this proportion depends on a great many factors, it is difficult to draw conclusions about the actual level of bearing currents. In addition, common mode current can also occur without bearing currents. Nevertheless, if the common mode current is very low, it can be assumed that no harmful circulating bearing currents and no harmful rotor ground currents occur. In addition, the effectiveness of countermeasures can be accurately evaluated by measuring the common mode current before and after the measure is applied.

Measurement of high frequency discharge energy

Every discharge in the bearing also leads to high frequency energy radiation, thus a Radio Frequency (RF) signal. Since this radiated discharge energy depends on the size of the bearing and is therefore also small in the case of small motors, detection can be difficult. The advantage with measuring the high frequency discharge energy is the contactless and thus extremely convenient measurement using an RF probe in order to detect the RF signal.

Countermeasures

Various countermeasures exist for harmful bearing currents. Here too, the effectiveness and selection of countermeasures depend on the bearing current type. In general, good high frequency earthing is recommended.

Symmetrical, shielded motor cables

The use of symmetrical, shielded motor cables with shielding connected at both ends provides very good protection against rotor ground currents. Compared to other countermeasures, these cables offer a further advantage insofar as the load is also protected.

The use of symmetrical shielded cables has no significant impact on circulating bearing currents and discharge bearing currents.

Other measures that can prevent rotor ground currents while protecting the load are the use of insulated couplings and the fitting of a good, high frequency bonding connection between the frames of the motor and the driven load. These measures also have no impact on the other bearing current types.

Bearings

The use of special bearings prevents electrical discharges in the bearing despite increased bearing voltage. Hybrid, ceramic and insulated bearings with an inner coating have become particularly popular.

- **Discharge bearing currents:** both bearings must be designed as hybrid or ceramic bearings. Insulated bearings do not prevent discharge currents. Another option is using bearings with special lubrication (low resistance). However, these bearings only prevent discharge currents and are not recommended due to a lack of long-term experience.
- **Circulating bearing currents:** it is sufficient to use a hybrid, ceramic or insulated bearings; preferably on the non-drive end (NDE).
- **Rotor earth currents:** both bearings must be designed as hybrid, ceramic or insulated bearings.

Shaft grounding brushes

When shaft grounding brushes are used, there must be a good, low-impedance contact between brush and shaft.

- **Discharge currents:** it is sufficient to equip one bearing with a shaft grounding brush.
- **Circulating bearing currents:** both bearings must be equipped with a shaft grounding brush.
- **Rotor ground currents:** it is sufficient to equip one bearing with a shaft grounding brush. However, there is a risk that the rotor ground currents will continue to cause damage in the load.

Common mode chokes

Common mode chokes reduce or prevent circulating bearing currents and rotor ground currents. However, care must be taken to ensure that the common mode choke is correctly rated. Discharge currents are not reduced by common mode chokes.

Filter or control patterns that suppress the common mode voltage

Filters that reduce or suppress the common mode voltage are effective with all bearing current types.

Design

Since the occurrence of the current, the level of the current and thus also the harmfulness in the bearing depends on the entire system, any bearing currents should already be factored into the design and tendering process. Otherwise, problems can arise, especially if the VFD and motor are purchased from different suppliers.

In existing installations, if there is any suspicion, one of the above measurements can be used to determine whether bearing currents are occurring. If the shaft is accessible, it is recommended to measure the voltage between frame and shaft. As a rule of thumb, bearing voltages below 5 V do not indicate harmful bearing currents. The decisive factor is the time course of the bearing voltage and not its effective value, as described in the Measurement section.

In very general terms, the following measures can be recommended to prevent harmful bearing currents:

- For all motors: good, high frequency earthing of the motor frame prevents rotor ground currents.
- For motors of low and medium power with DC link voltage from 560 V: provide a countermeasure for discharge bearing currents, e.g. use of a shaft grounding brush.
- For motors from approx. 100 kW: provide a countermeasure for circulating bearing currents, e.g. insulated bearing/hybrid bearings for the non-drive end (NDE).
- For motors from approx. 400 kW in addition: provide further measures such as common mode filters.

Additional information

Notions and units

Designation	Abbreviation	Unit	Indices,explanation
Frequency	f	Hz	N: Net M: Motor
Variable-frequency drive	VFD		
High frequency	HF		
Radio frequency probe	RF probe		Device for measuring radio frequency signals
International Electrotechnical Commission	IEC		
Institute of Electrical and Electronics Engineers	IEEE		
Power	P	W	
Non-drive end	NDE		Also fan side, B side.
Tension	U	V	N: Net M: Motor
Technical Committee (of IEC)	TC		
Technical Specification (of IEC)	TS		
Alternating current	AC	A	
Time	t	s	

IEC Specifications

- General conditions for bearing currents: IEC TS 60034-25, 2014: Rotating electrical machines – Part 25: AC electrical machines used in power drive systems – Application guide, Chapter 8.
- General conditions for installation: IEC TS 60034-25, 2014: Rotating electrical machines – Part 25: AC electrical machines used in power drive systems – Application guide, Chapter 9.
- Additional information for different motor technologies: IEC TS 60034-25, 2014: Rotating electrical machines – Part 25: AC electrical machines used in power drive systems – Application guide, Chapters 10 to 19.

Sources and reference literature

- Technical Instruction No. 5 – Bearing currents in modern AC drive systems, ABB Automation, 2001
- Muetze, «Bearing Currents in Inverter-Fed AC Motors», Dissertation, Technical University of Darmstadt, Germany, 2004
- Muetze und A. Binder, «Practical Rules for assessment of Inverter-Induced Bearing currents in Inverter-Fed AC Motors up to 500 kW», IEEE Transaction on Industrial Electronics, June 2007.
- Impact Energy, Merkblatt Nr. 25 – Frequenzumrichter (written in German)

Editorial remark

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