Influence of material and thickness of slot insulation of the electric machine on the bearing voltage ratio

K Vostrov¹, V Frolov¹, V Shestakov¹, E Popkov¹, A D Mitrofanov²

¹Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia
²Kazan State Power Engineering University, Kazan, Russian Federation

Abstract. The Modern electrical drive systems which able to operate in variable-speed mode became a conventional setup since power electronics-based frequency converters became wide spread. Nevertheless, specific parasitic phenomena of bearing currents always accompanying drive systems fed by frequency converters. In electrical machines, especially in small size motors, major role in parasitic current patch plays capacitance between stator winding and rotor surface. In this paper it will be considered influence of winding insulation type on the bearing voltage ratio and corresponding winding-to-rotor capacitance.

1. Introduction

One of the reasons for the failure of modern variable speed electrical drive systems is the premature failure of the bearing units of the drive motor. When the motor is powered by a frequency converter, the accelerated wear of the bearings may occur. The bearing failure usually happens due to the parasitic currents flowing through them because of undesired voltage induced on the drive shaft due to the operation of the inverter. The mechanism of bearing currents occurrence and its variety have been repeatedly described by various authors [1-8].

The origins of bearing currents flowing can be generally separated into two groups. The first and convenient origin of bearing currents is related to the machine’s inaccurate geometry. The asymmetry of the magnetic system of the drive motor can arise because of reasons such as: different values of the resistances and inductances of the stator and rotor windings; clearances in the joints between the packages of the stator and rotor lamination stacks; asymmetrical arrangement of poles; uneven air gap between the rotor and the stator. The mentioned factors of electromagnetic imbalance are a consequence of the imperfect assembly of the drive motor and possible inaccurately in production technology or inappropriate operating conditions. The asymmetry of the electromagnetic system of the machine leads to the appearance of undesired potential on the shaft ends and other massive parts of the electric motor.

Another reason for the appearance of bearing currents caused by mechanical reasons may come from misalignment of the machine’s rotor. Due to mechanical imbalance, the rotor of the drive motor starts to make elliptical movements. Such a motion of the rotor causes electromagnetic imbalance of the drive motor, since the interaction of the magnetic fields of the stator and the rotor becomes pulsating. This leads to the inducing of potentials on the shaft ends of the electric motor, which causes bearing currents flowing.

It should be noted that such potential can be induced, even if the stator feeding voltage waveform is absolutely sinusoidal. The resulting voltage causes the appearance of bearing currents. Thus, the mechanical asymmetry and imbalance of the drive motor can cause bearing currents either in direct online or frequency converter fed drive systems.

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The second source of bearing currents is related to modern electrical drive systems and became a major one since frequency converters began to be widely introduced. The main reason for the appearance of bearing currents flowing in modern electric drives is the common-mode voltage. The three-phase voltage at the inverter output operating in the pulse-width modulation mode has the form of a high-frequency pulse sequence. Being generated with a shift, such sequences forming a 3-phase output and supply the motor terminals. Wherein the instant sum of the phase voltages is not equal to zero and forms a high frequency voltage between the motor’s neutral point and grounded parts of the motor. From the bearing currents arisen by such a mechanism only the drives fed by the frequency converter suffer.

Depending on the bearing currents flowing path, a different kinds of them are introduced:

1. Circulating bearing current, caused mainly by the machine inaccurate design, flows along the shaft inside of the machine and closes through the motor housing. Being passed through both bearings, circulating current causes its accelerated degradation.
2. Non-circulating bearing currents, which induced by common-mode voltage, flows from the motor’s stator windings to the grounded parts of the machine through the capacitance couplings and bearings. Depending on grounding conditions, such a current may damage either motor’s or driven load’s bearings.
3. Stator ground current appears due to common-mode voltage as well, but flows to ground point through stray capacitance between winding and stator and not endangers bearings. But, if motor grounding is malfunctioning, the stator ground current may flow through the load’s grounding connection, and in such a case, and in this case the bearings will be harmed, both the engine’s and the load’s.
4. Shaft current may occur in case of bad motor protection earth connection when either non-circulating or stator ground current flow through the shaft and further through the driven load to the load’s ground potential.

A schematic explanation of different kinds of bearing currents patch is presented in Figure [9].

![Figure 1](image_url)

**Figure 1.** Schematic representation of the electric drive and possible ways of leakage of the bearing currents through parasitic capacitances, where a) – circulating bearing current, b) – non-circulating bearing current, c) and d) – shaft current caused by winding to rotor and winding to stator capacitances respectively, e) – stator ground current.

In low power scale electrical machines, the predominant type of bearing currents are non-circulating currents caused by the flow of a high-frequency common-mode induced current through parasitic capacitances between the machine rotating elements and grounded parts.

It was reported about different techniques of bearing currents mitigation [1, 5, 10-15]

One of the methods to reduce non-circulating bearing currents is to increase the impedance of the elements that form its path. Taking into account that this current is mainly capacitive in nature, an effective and promising method is to reduce the parasitic capacitances of an electrical machine. The
largest contribution to the transmission of non-circulating bearing current belongs to the capacitance between the stator winding of the motor and the rotor surface [3,4]. There are a number of publications aimed at studying and reducing this capacity [13 – 15, 26-29]. To assess the machine's risk of non-circulating bearing currents, the bearing voltage ratio ($BVR$) is commonly used. The ratio shows the share of the winding-to-rotor capacitance from to the sum of all parasitic capacitances and usually is calculated by the equation [3]:

$$BVR = \frac{C_{wr}}{C_{wr} + C_{sr} + 2C_b}$$  \hspace{1cm} (1)

where $C_{wr}$ – capacitance between winding and rotor, $C_{sr}$ – capacitance between stator and rotor, $C_b$ – capacitance between inner and outer bearing races.

Bearing voltage ratio will be used further in this paper to evaluate and compare results. Current study will be focused on the one certain possible winding-to-rotor capacitance reduction by applying different insulating materials with different thickness as a winding insulation at slot opening.

2. Objective and methods

The purpose of this work is to investigate the influence of the use of various insulating materials on the bearing voltage ratio, and, as a consequence, on the amplitude of the induced bearing current.

The method of carrying out the research implies the examination of the one slot of the electric motor with a power of 30 kW. Modeling is done by the finite elements method investigation of the slot with the use of different types and sizes of slot insulation. Figure 2 shows the stator slot of the electric machine being modeled, on which the main elements have been modeled are marked.

As slot insulation, the materials listed in Table 1 were reviewed. [16-18].

Table 1. List of reviewed materials.

| Material                  | Dielectric permeability |
|---------------------------|-------------------------|
| Mikanit                   | 2                       |
| Polyethylene terephthalate| 3.1                     |
| Fiberglass                | 5.5                     |
| Plastics with inorganic filler | 7.7             |

Also in the research the influence of the thickness “d” of the materials used was investigated. The results of the studies are shown in Figure 3. When calculating the bearing voltage ratio, the capacitance of one bearing was assumed to be at average level of 0.5 nF [19], while the capacitance between the rotor and the stator assumed as 1.3 e-11 F [20-25].
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3. Summary
The analysis of the obtained data shows that for the maximum possible reduction of the bearing currents of the drives it is recommended to use the most possible thin insulating materials with a lowered coefficient of dielectric permittivity.

Since non-circulating bearing currents are most affected by low-power machines, the use of ultrathin micaceous plates as insulation for slots is most justified in such machines. Also Figure 3 shows that when using other materials with higher dielectric permittivity, the bearing voltage ratio may still remain above 1.5% if thin films of such materials are used. Increasing the thickness of the insulation layer adversely affects the electrical machine regardless of the insulation material used.

Thus, when designing electrical machines powered by a frequency converter, first of all it is necessary to strive to utilize the smallest possible thickness of slot insulation. In addition, the use of materials with a lower dielectric permeability will also contribute to the suppression of parasitic bearing currents.

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