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Shaft Grounding Solution(s) for Bearing Protection

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Executive Summary

Besides classic shaft voltages generated by an asymmetrical design of the stator sheet package modern frequency converters for electric motors can also cause bearing currents which then similarly end up in bearing failures. The challenge to develop a robust, compact and cost-effective preventive product for the bearings was solved by a new shaft grounding system. KACO's new material combination of a highly conductive PTFE with a silver coating overcomes disadvantages of known state of the art designs. Further improvement is given by a specifically designed running surface. Both function and long-term service properties have been investigated and are presented.

Keywords: component, electric drive, EV (electric vehicle), motor, powertrain

1 Introduction – Classification of the topic

Bearing currents have been known for many decades. Irregularities in the structure of the stator sheet package can even lead to a circular flux in the sheet package by supply with sinusoidal voltages. This magnetic flux induces a voltage the so called shaft voltage, which is measurable between the shaft ends. If the shaft voltage exceeds the insulation strength of the lubricating film of the bearings, a power frequency bearing current flows. [1]

Today, modern frequency converters are used for precise speed and torque control of electric motors. But this is not uncomplicated and it is responsible for additional emergence of bearing currents. Beside the "classical" shaft voltage, the bearing currents generated by the frequency converters can be divided into the following three formation mechanisms:

1. Capacitive reload currents (du / dt current) and discharge currents (EDM current),
2. High-frequency circular current through the leakage current and
3. Rotor-grounding currents

These bearing currents lead to an electrical overload of the bearings, with the typical visual appearances:

1. Matted track and rolling element surfaces, so called pittings,
2. White etching cracks under the surfaces,
3. Periodic track corrugated structures (washboard like structures)and
4. Harmful chemical change of the lubricant inside the bearing.

In addition to increased noise, these damages ultimately lead to a complete failure of the bearings. [2]

The battery voltage level or the switching frequency level of the inverters are just two of the many influencing factors that have a significant impact on the bearing current. Without effective protection, these parasitic currents can lead to premature bearing failure, resulting in motor failure. A special shaft grounding system has been developed to protect the bearings and a safe discharge of the current to the ground. The shaft grounding system consists of the shaft grounding ring and the corresponding sleeve. The KACO shaft grounding systems are a reliable and cost-effective way to minimize electrical bearing damage in frequency converter controlled electric motors and systems.

2 Development

A main focus of the company KACO GmbH + Co. KG is the confident sealing of rotating shafts for e. g. combustion and electric motors. These sealing functions can only be solved through the use of suitable materials and specific know-how. In the development of the shaft grounding rings, these knowledges were used and the task definition was modified and adapted. In addition to the high peripheral speeds of the rotor shafts and the usual temperatures in the automotive industry, the following additional priorities for shaft grounding rings must be considered:

1. Low electrical impedance of the shaft grounding system, consisting of shaft grounding ring and mating surface over a high frequency range,
2. Optimal contact between shaft grounding ring and mating surface, with the lowest possible radial force,
3. Independence of the direction of rotation,
4. Robust design for small installation spaces and
5. Cost-effective complete system

The central grounding function is carried out by the conducting element, which is in the case and is fixed by the clamping case (Figure 1). This conducting disc consists of a filled PTFE compound, which was developed in extensive series of tests for the ideal balance between electrical and mechanical properties. Good contact between the shaft and the conducting element is important for low impedance. Nevertheless, the radial force on the shaft must not be too high, so that the friction torque and the friction power do not affect the temperature level. Again, numerous design studies, including FEA support, have been carried out to obtain a well-balanced system.

The conducting element is completely coated with a conductive coating in order to get the impedance to a very low level. Case and clamping case can be made of suitable aluminum or stainless steel alloys tailored to the application. By using these materials a good electrical conductivity is ensured and at the same time a good corrosion protection is given. It has proven useful to attach two hydrophobic felt discs to the carrier housing to protect the shaft grounding ring from environmental influences from the outside. Since the rotation of the shaft in this contact system is a dry friction, the wear particles of the conducting element can be imbedded by these two disks. The mating partner was also examined in extensive experiments. Systems that provide a silver-containing surface have proven to be advantageous. The sleeve material is an alloyed stainless steel. This results in an overall system that has very low impedance. Overall, the design and material selection result in a cost-effective product that only requires a small amount of additional space.

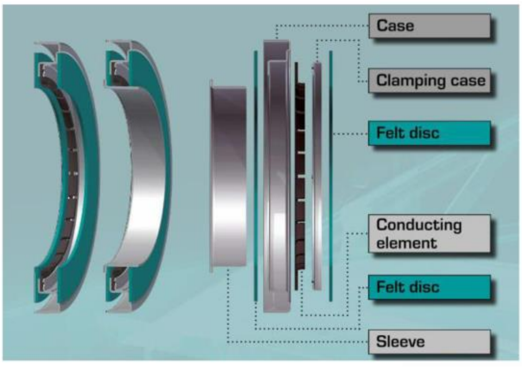

Figure 1: Typical construction of the shaft grounding ring and the sleeve

The shaft grounding ring is pressed into the housing of the application and the silver coated sleeve is pressed on the shaft. This results in the optimally shaft grounding system.

But for other applications the construction of the grounding system can be turned. This means the shaft grounding ring with the conducting elements and the two felt discs is pressed on the shaft and the corresponding running surface is mounted on the case (see figure 2). So the shaft grounding ring rotates with the speed of the shaft and the conducting elements were pressed uniform by the centrifugal force on the coated sleeve. Even on special environmental conditions can be reacted to, with other suitable and available coatings for the grounding elements of the ring as well as for the mating surface.

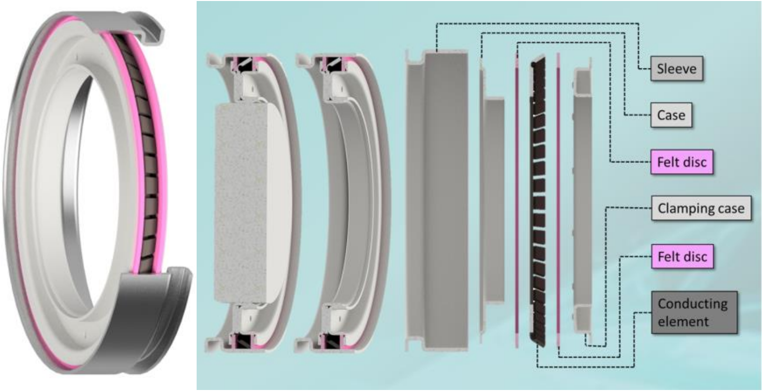

Figure 2: construction of a turned shaft grounding ring pressed on the shaft and the sleeve is mounted on the housing

To protect the conducting elements during the transport between two facilities or on the assembly line a suitable protection cap can be necessary. One possible design is shown on figure 3. The shaft grounding ring with this special cap will be delivered as a complete system and will be pressed on the shaft. At the appropriate assembly station, the protective cap will be removed by means of suitable predetermined breaking points.

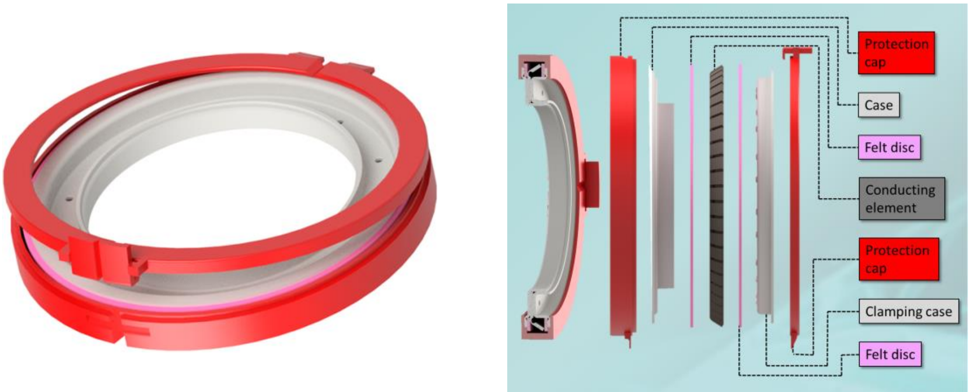

Figure 3: shaft grounding ring with protection cap

3 Measurement and Results

In order to qualify the shaft grounding system, a corresponding test field was set up at KACO, suitable measuring methods and evaluation algorithms were developed. Detailed customer-specific overall solutions were also developed in cooperation with many automotive customers in order to confirm the effect of the shaft grounding system.

When selecting the tests, tests from the fields of mechanical tests, chemical tests and climatic tests, service life tests as well as application-specific testing's are taken into account.

From the field of mechanical testing, e.g. free fall, mechanical shocks, vibration tests or dust ingress tests are carried out. But also assembly and holding forces are determined in the geometrical extreme positions.

The storage of the grounding system under various conditions in various chemicals belongs to the field of chemical testing.

The greatest variance in test possibilities is in the climatic test category. Thermal shock, damp heat or harmful gas tests are only three examples of tests which were done in this testing scope.

In the field of service life tests many endurance runs were done according a customer specified running profile, under high speed, under min and max temperature or special runout of the shaft or eccentric assembly.

Tests which were done based on the special requirements of the application are e. g. cold start, silt or water immersion tests.

For the design validation some test were done one after the other with the same grounding system. This serial test sequence increases the intensity of the test drastically. The test duration, test intensity or the rotational speed for all the different tests were well defined together with the customers.

Three important investigations are described in more detail in the following.

Endurance runs according to a special customer defined running profile over a long test period are almost standard test. An example of such an endurance test is shown in Figure 4. A special speed profile was tuned with the automotive customer in the range of 0 - 12,500 rpm. This profile was run through in several cycles, resulting in total test duration of 1,000 h. The impedance measurements were carried out after each single cycle for defined speeds and also during the continuous run measurements were made every half hour. A specially developed evaluation method was used to determine the impedances of the individual shaft grounding rings, which are on average 0.43 and 0.61 Ω for the two illustrated shaft grounding rings.

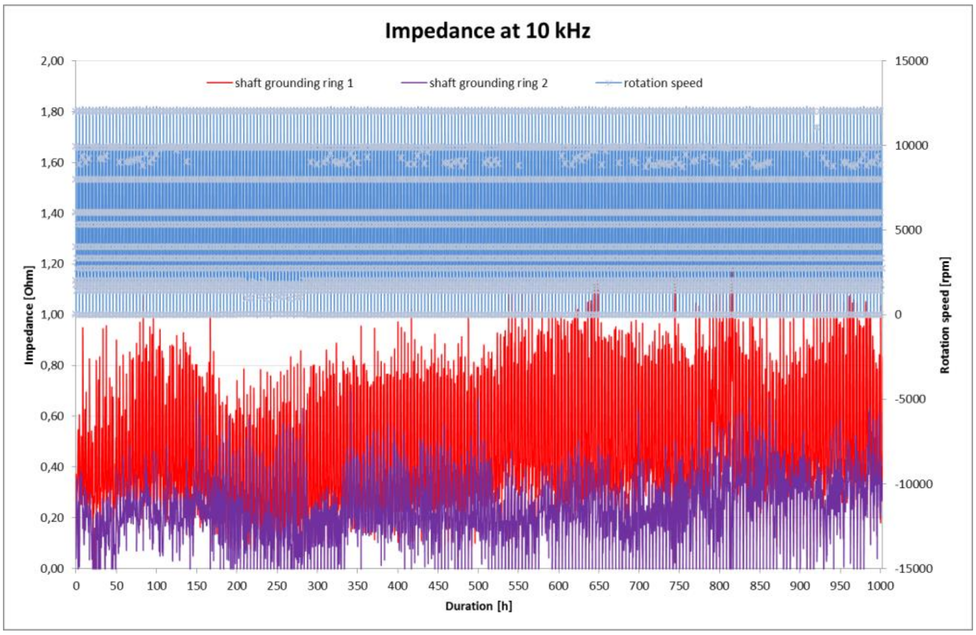

Figure 4: Impedance at 10 kHz of shaft grounding rings with a spezial speed profile

The mode of operation of the shaft grounding system is shown in Figure 5. It can be clearly seen that when using a shaft grounding ring, the high-frequency voltage is reduced.

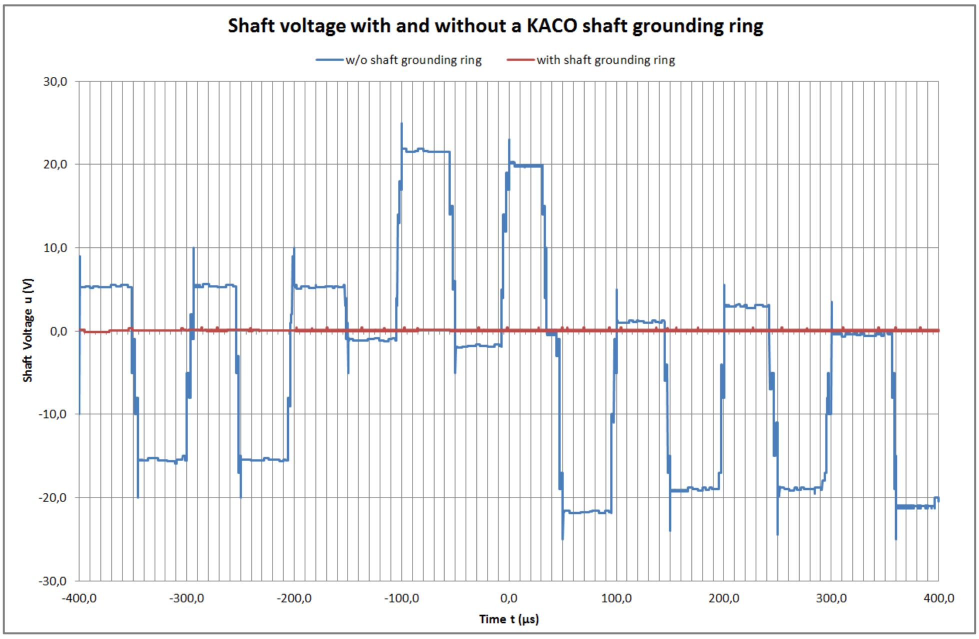

Figure 5: Shaft voltage with and without a KACO shaft grounding ring

In many cases a high speed endurance run was performed after the above described profile endurance run. Several shaft grounding rings were simultaneously tested on suitable test rigs at rotation speed of 15,000 rpm. These investigations were carried out over more than 300 h. An example of such measurement results of the electrical resistance are shown in Figure 6. The resistance is smaller than 1,5 Ω during the complete runtime.

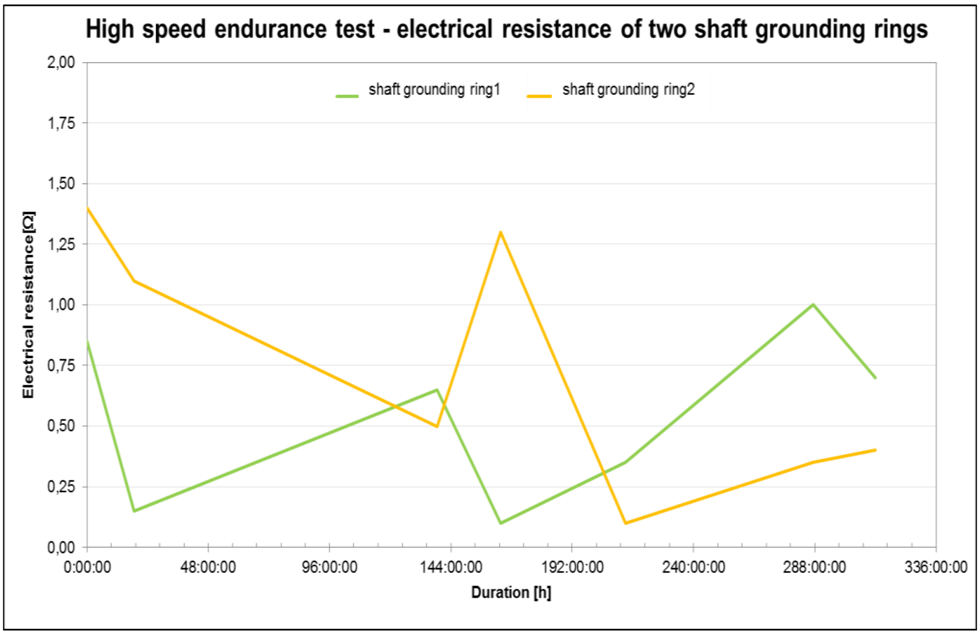

Figure 6: measurement of the electrical resistance during the high speed endurance test

Another important aspect that was considered during development is the friction. Important for the grounding function is good electrical contact between the conductive elements and the shaft or sleeve. Too high radial force of the conductive elements on the shaft leads to high friction with corresponding temperature increase. On the other hand a too low contact pressure of the pairing leads to poor mechanical and electrical contact and thus to insufficient grounding function. Friction measurements are standard investigation procedures at KACO. After a running-in phase, friction power and friction torque are determined at different rotation speeds. Measurement results for a shaft grounding system are shown as an example in Figure 7. In this example the running surface has an diameter of Ø 56,5 mm. The friction torque even for 15,000 rpm is lower than 0,05 Nm.

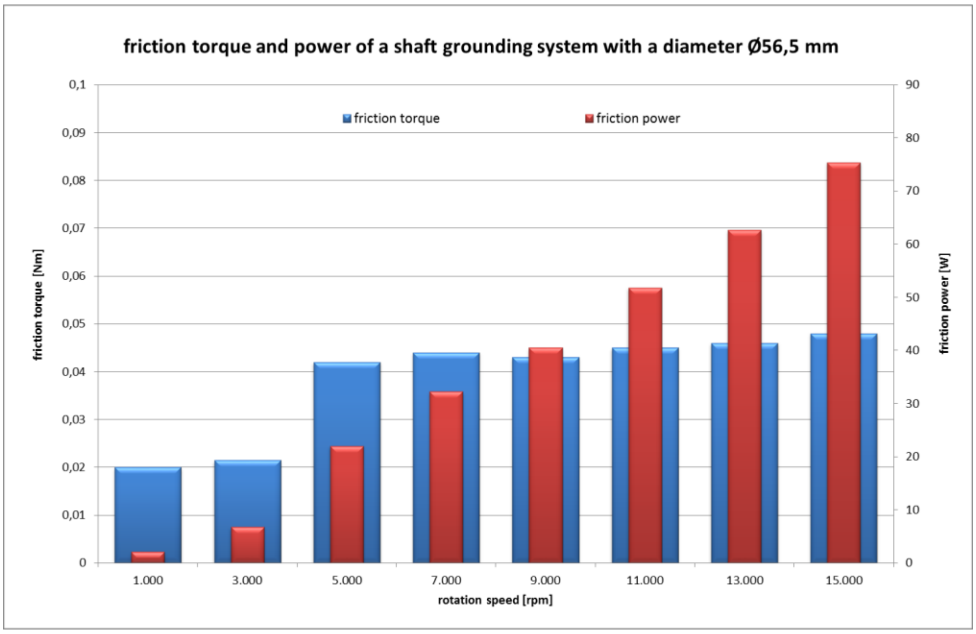

Figure 7: measurement of the friction torque and power of a shaft grounding system

4 Summary and new approaches

With the shaft grounding ring it is possible to obtain an effective bearing and gearing protection for electric motors and transmission systems. This was confirmed by extensive test programs during the development of the shaft grounding system. The best procedure to prevent bearing failures due to capacitive induced shaft tensions is to install a silver coated sleeve and a shaft grounding ring with special coated conductive elements to safely provide a "least resistance" path away from motor bearings to ground. To protect against high frequency circulating currents, break the circulation by installing insulated or ceramic bearings on the non-drive side of the electric motor and installing a shaft grounding ring on the drive side. Furthermore, by using the shaft grounding ring, a significant reduction of the impedance in the AM frequency range is visible. KACOs shaft grounding ring is independent of the direction of rotation and has a long service life. New generations with lower impedance, improved design features, less wear and cost advantages are currently on the test benches and in testing by automotive customers. In addition, grounding systems are being developed that also can work directly in oil or oily environments. This makes KACO the qualified development partner for shaft grounding systems.

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Authors

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After studying the Materials Science at the Technical University in Berlin, I worked for a huge surface coating company. Since 1996 I have been employed at KACO GmbH + Co KG as a graduate engineer in the development department for sealing systems and multipole encoder wheels. Currently I am team leader in the field sensors, electrics and magnetics.</td></tr>
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In March 2018 I finished my studies in electronics and information technology with focus on power electronics. After my studies, I began to work as an advanced engineer in the field of e-mobility at KACO GmbH + Co. KG in Kirchardt.</td></tr>
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