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Preventing lightning damage in bearings by using mechanical preloading

Frank Leferink[a,b,*]

[a] University of Twente, Enschede, The Netherlands
[b] THALES, Hengelo, The Netherlands

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ABSTRACT

High positioned systems such as wind turbines or radar system onboard a ship can be easily struck by lightning. The lightning current has to be conducted via defined paths to prevent damage. A key element to protect is the bearing system between the rotating and stationary part. Providing a bypass current path via additional measures such as a slip ring is the conventional way of protecting bearing. The arcing due to high voltage difference between rollers and raceway is however the main cause of damage to the bearing system. It is commonly assumed that, if the wind turbine blades, or the radar, is rotating, the lubrication between the rolling elements and the raceway is a non-electrical conducting hydrodynamic lubrication layer, and thus high voltages can be developed. But if the bearing is sufficiently preloaded it is still providing a conductive path via boundary lubrication. No arcing occurs, and no damage. The concept of pre-loading the bearing system has been evaluated using many experiments on stationary and rotating bearings, and after performing endurance testing.

1. Introduction

Wind turbines can be easily struck by lightning [1–7]. The most common damage is the electronic control system, while the most visible damage is the lightning damage to the composite blades. The bearing system is also a vulnerable part [8–11], although less investigated. The risk of radar equipment being struck by lightning is much higher in the littoral, i.e. waters near the coast, than in the blue water areas, far away from the coast [12]. Naval vessels were operating in the blue water but this is changing rapidly to the littoral. Radar systems are often located at a high position and are therefore also vulnerable to be struck by lightning. Also for rotating radar systems the bearing system is the key component between the rotating and stationary parts of a radar system. No public data was found on lightning damage to radar bearings, but the problem can be compared with that of bearings on wind turbines [12]. The main-shaft bearing is one of the most involved parts [8], and lightning damages to these bearings can result in high costs of maintenance. In the main standard IEC 61400-24 [1] only very generic information can be found, such as that the bearing should be protected. In Ref. [13] lightning tests on an electric vehicle are described showing that the lightning current path flows between the metal alloy of the wheel and ground. No further investigation on the bearing is reported. In Refs. [2–4,8] it is suggested that the damage of the main-shaft bearing is caused by flashovers within the bearing lubricant, or arcing, resulting in pitting. The possibly following high current after the arc could result in overheating and welding, but this latter phenomenon is not described in literature. In a conventional system, slip rings are conducting the lightning around the bearing, in order to prevent arcing. This is also the conventional approach protecting arcing in radar system bearings. The slip ring consists of a series of carbon brush elements divided over the circumference of the radar antenna drive creating an electrical conductive path for the lightning current. The disadvantage of these brush elements is the wear, resulting in very regular maintenance, for instance once per year. Furthermore the wear is causing dust, thus pollution. A slip ring around the main shaft is also the generic means to protect the bearing of wind turbines against lubricant flashovers, since the bearing is a very critical component to exchange. Because of this protection, practical experience with lightning damage to wind turbine bearings is scarce, wind turbine bearings are not normally checked after lightning strikes [2,3]. Few investigations of the damaging effect of lightning current on bearings have been carried out. In Ref. [11], the tests were exaggerated by reducing the number of rolling elements, to force the current through only 1 or 2 such elements. But it was

* Correspondence to: University of Twente, EWI Faculty, P.O. Box 217, 7500 AE Enschede, The Netherlands.
E-mail address: frank.leferink@utwente.nl

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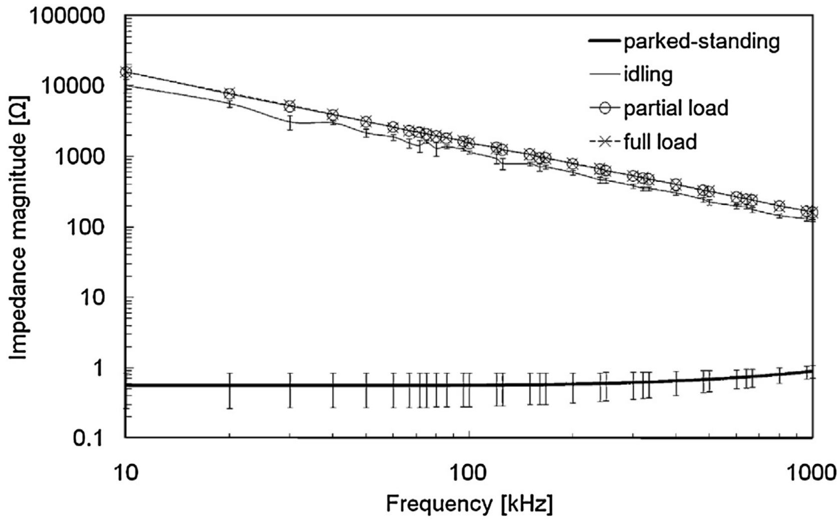

Fig. 1. Electrical impedances of the reduced scale bearing model, from [10].

also concluded that the damages produced by an arc can be bigger than the current conduction damage. In the following sections the stationary bearing, boundary lubrication and rotating bearing, and lightning experiments on a rotating preloaded bearing solutions are discussed, showing the advantages of mechanical preloading of bearing to prevent damage due to lightning currents.

2. Stationary bearing

A new trend in architecture during the last few years is the use of retractable roofs in stadiums. These roof structures have no fixed connections to ground; instead they have thousands of moving contact points. Traditionally, for a building or a fixed-roof stadium, lightning rods are grounded to the roof steel, the roof steel connected to columns, and the columns connected to a ground grid. But for a retractable roof it is likely that the current will find its way to ground via bearings. This problem is described in Ref. [14]. Lightning current tests have been performed on a greased bearing in stationary condition, and it was found that no damage occurred to rolling elements and raceways. The retractable roof has been used in many areas where lightning has hit the structure without damaging the structure. This situation is comparable to a stationary radar, i.e. a radar which is normally rotating but is in a non-active mode. The weight of the radar in a parked position is pressing through the lubricant and a direct contact between rolling elements and the raceway is made. Then no arcing is possible, and no pitting results. Comparable conclusions have been drawn in Ref. [11] where lightning currents were conducted through bearings. The identical tests to a rotating and a stationary bearing only resulted in damage to the rotating bearing. It was concluded that the cause of damage is arcing between rolling elements and raceways at the breakdown points through the insulating hydrodynamic lubrication layer present in the rotating bearing. This was also concluded in Ref. [15], and confirms the assumption that the arcing resulting in pitting is the cause of damage, and not the current which might cause locally heating. Of course, in case nearly all rolling elements are removed, such as in Ref. [11], then only one roller has to conduct the current resulting in a very high local current density, and inevitably damage.

In Refs. [9,10] models for the bearing impedance have been developed, based on extensive measurements of a 1:20 reduced scale model of typical main shaft wind turbine bearings. To replicate the mechanical load conditions, also scaled mechanical forces, tilt-moment and rotation speed that appears in real scale main shaft bearings were used. Fig. 1 shows the measured impedances of the reduced scale bearing model, for parked, idling, partial load and full (wind) load. In the parked-standing mode, the bearing impedance shows a low impedance (ohmic) behavior that can be justified considering that the bearing elements are in metallic contact due to the null rotation speed that does not allow for the formation of the lubricant film. But in the idling, partial and full wind load conditions, the bearing can be modelled by a capacitance suggesting that there is film lubrication between the roller and the raceway. This is in line with the assumption in Ref. [5], which assumes a film of 50 μm thickness at the operational speed of a wind turbine (20–30 RPM).

3. Boundary lubrication

If a radar antenna is rotating a hydrodynamic layer of lubricant is developed in the bearing which will result in an insulating layer. If a lightning strikes the antenna, a high voltage is developed, and flashover will occur, causing a spark, which will ultimately result in pitting on the race and rollers even at relatively low current levels. To prevent damage, carbon brushes in a slip ring are often used to provide a low impedance current path. Preloaded bearings have been used many times to reduce the variations in movements, to attain the required built-in stiffness and running accuracy. Experiments with an electrostatic discharge gun on bearings showed that stationary bearings were conducting (as expected), rotating bearings were not conducting due to the oil film (as expected), but that rotating preloaded bearings were also conducting. This last effect is against the conventional knowledge and unexpected. However, the actual friction regimes for sliding lubricated surfaces have been broadly categorized into solid/boundary, mixed, or fluid friction, on the basis of the Stribeck curve [16–18]. In general, unbreakable lubricating films are required to prevent intimate contact between mating surfaces, which are produced by fluid film lubrication. In practice, however, the transition from fluid film lubrication to boundary lubrication occurs with increasing load or decreasing relative velocity, which leads to an increase in the coefficient of friction. Stribeck, and others, studied the variation of friction between two liquid lubricated surfaces as a function of a dimensionless lubrication parameter $\eta N/P$, where η is the dynamic viscosity (Ns/m^2), N the sliding speed (m/s) and P the load projected on to the geometrical surface which is usually load per unit length of bearing in N/m. An example is shown in Fig. 2. In the film lubrication regime the rolling elements and raceway are completely isolated via a thin layer of lubrication oil. In the boundary lubrication regime the film