The Wind Turbine Design Guideline DG03: Yaw and Pitch Rolling Bearing Life Revisited – An Outline of Suggested Changes

Preprint

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The Wind Turbine Design Guideline DG03: Yaw and Pitch Rolling Bearing Life Revisited – An Outline of Suggested Changes

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Abstract: The Design Guideline 03 (DG03) published by the National Renewable Energy Laboratory in 2009 is widely used in the wind industry. It allows engineers to get acquainted with design aspects and methodologies to determine pitch and yaw bearing static capacity and fatigue life. The combination of the detailed theoretical descriptions and practical examples makes it a highly application-oriented document. Since its publication, the knowledge about oscillating bearings, slewing bearings, and wind turbines has grown significantly. Some aspects of the DG03 need updates to reflect the current state of the art. This work covers proposed changes for an upcoming revision of DG03.

1 Introduction

Pitch bearings, also called blade bearings, connect the wind turbine rotor hub and blades. They allow the blades to turn about their primary axis. This pitch movement serves to control power output and loads of wind turbines. Yaw bearings connect the tower top with the nacelle and allow the entire nacelle with the rotor to turn into the inflowing wind. Both bearing types are commonly large rolling bearings, also called slewing bearings [1]. While commercial pitch bearings are always rolling bearings, yaw bearings are also available as journal bearings. Rolling yaw and pitch bearings are commonly grease-lubricated. Unlike rolling bearings in other turbine locations, these oscillating bearings do not have full rotations during operation and do not have an applicable standardized approach for rating and life analysis.

The Design Guideline 03 (DG03) by the National Renewable Energy Laboratory (NREL) was published in 2009 and covers several design aspects of these two bearing applications [2]. The document takes a common perspective of wind turbine designers and bearing manufacturers. It does not go into any details of internal bearing design like roller end geometry or hardening parameters, and it does not cover turbine controller aspects or aero-elastic simulations.

The DG03 does not reflect today's state of the art, yet it is referred to by current turbine design guidelines [3]. NREL and Fraunhofer Institute for Wind Energy Systems (IWES) will update the guideline and publish it in 2023. Table 1 compares the major differences of the 2009 and 2023 versions of DG03.

2009 DG03 TOC	2023 DG03 TOC	Remarks
Design Types	*Basic Principles*	Includes Design Types
Summary of Calculation Methods	Summary of *Damage Modes and* Calculation Methods	
	Finite Element Models	See Section 2
Calculation of Bearing Fatigue Life	Calculation of Bearing Fatigue Life	See Section 3
Bearing Static Capacity	Bearing Static Capacity	
Estimation of Case-Core Interface Depth	Estimation of Case-Core Interface Depth	
Effective Lubrication	Effective Lubrication *and Wear Prevention*	See Section 4
Bearing Friction Torque	Bearing Friction Torque	See Section 5
Miscellaneous Design Consideration	Miscellaneous Design Consideration	

Table 1 Comparison of table of contents (TOC) between the DG03 2009 and 2023 versions.

Section 2 highlights the importance of and requirements for finite-element models of pitch and yaw bearings. Section 3 focuses on the calculation of rolling contact fatigue. Section 4 focuses on wear prevention in oscillating slewing bearings. Section 5 then covers the state of the art in slewing bearing friction calculation and measurement. Section 6 concludes this work and presents an outlook on the update process of the DG03.

2 Finite Element Models

With regards to finite element analysis (FEA), the 2009 version of the DG03 states on page 11 that "actual experience (FEA analysis) with the effects of various mounting structures on bearing life is limited." Scientific research and industrial practices have contributed significant experience to this field since then. Proven and reliable methods to apply loads, modelling high numbers of rolling bodies and bolts, and performing detailed analyses with sub-models allow the design of more reliable and efficient bearings [4–11]. Because of its more complex structural interfaces, this section focuses on pitch bearing finite element models. The methods are applicable to yaw bearings as well.

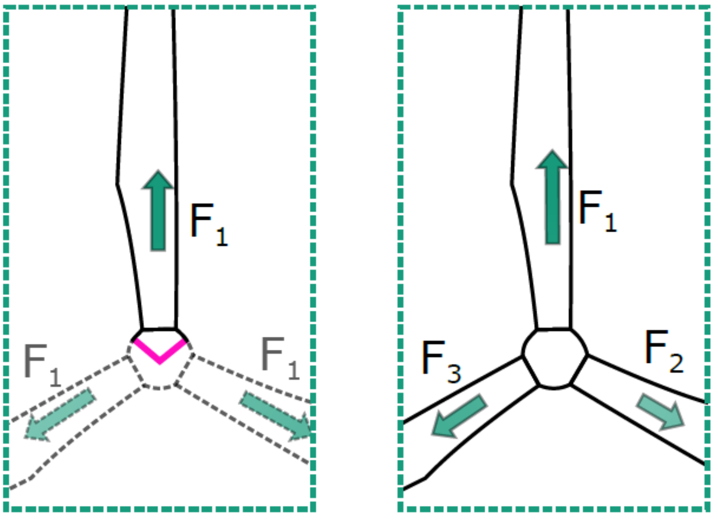

Figure 1: One-third and full rotor star model sketch (©Fraunhofer IWES / Matthias Stammler)

The DG03 update will incorporate definitions on different model types like full rotor star and one-third rotor star models (see Figure 1 and Figure 2). Full rotor star models consist of a fully modelled hub with three blades and at least one blade bearing. One-third rotor star models have a 120° section off the hub and a symmetry constraint on the cut surfaces. Models with hub and blade are not the state of the art and will not be part of the update.

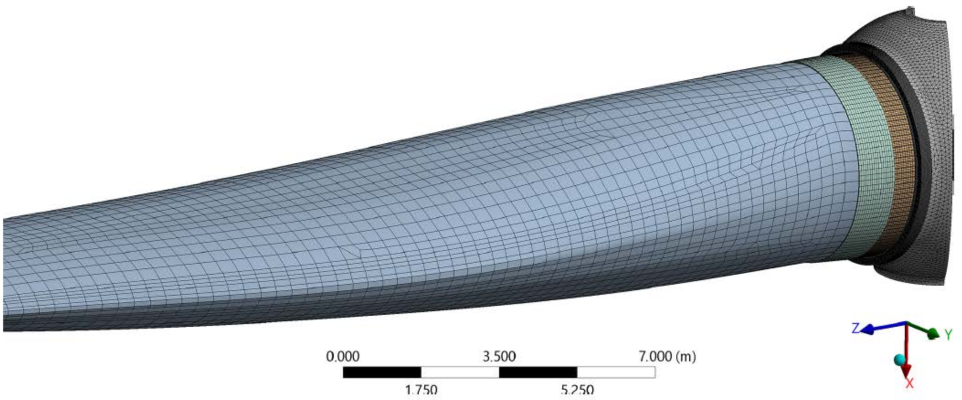

Figure 2: One-third rotor star finite element mesh (©Fraunhofer IWES / Florian Schleich)

The update will also cover the load application on the blades and the contact definitions as well as the modelling of the rolling bodies. With any models using nonlinear springs to represent rolling bodies, a rotation of the bearing rings must be prevented, as this influences the load results of the rolling bodies. Such a 'pitch lock' in turn influences the deformation results. A trade-off between desired and undesired consequences is necessary, and different pitch-locks will be discussed in the updated DG03.

3 Rolling Contact Fatigue

The rolling contact fatigue methods described in the 2009 version of DG03 are all heavily based on scaled models of small, rotating bearings. Since then much progress has been made, and therefore new results on the calculation of rolling contact fatigue life will be included in the guideline. Some previous assumptions will be removed to simplify the calculation and to increase its accuracy. The adaptations to be made are based both on theoretical considerations as well as rolling contact fatigue tests performed by Fraunhofer IWES and its research partners.

The original version of DG03 is very conservative in its calculation, particularly with regards to usage of the lubrication factor (a_{ISO} or a_3) [12]. This value is generally going to be as low as 0.1 for any rotor blade bearing due to the slow speed of movement. However, with modern lubricants that contain additives and are proven to work even under adverse circumstances, such a severe reduction is often too conservative.

Since blade bearings oscillate, the DG03 includes an adjustment for oscillating rolling contact fatigue calculation in which the load rating C is adapted according to an approach derived by Rumbarger. However, the literature includes several other approaches which produce different results. Based on a review of the existing literature, the adaptation of the ISO- and ANSI/ABMA-standards is performed in a manner that is consistent with the behavior seen in blade bearings.

Moreover, the calculation of C in the 2009 version of DG03 is based on ISO and ANSI/ABMA but includes a slight error that results in a load rating which is inconsistent with the aforementioned standards. This will be corrected to ensure consistency.

The equivalent load P that is required for rolling contact fatigue life calculation cannot be easily calculated according to the simplified formulae in commonly used standards. The 2009 version of DG03 therefore includes simplified approaches for the calculation of P which, however, lead to different results. Like with the consideration of oscillation above, we aim to unify these approaches and define one or several methods that produce results consistent with a proper application or enhancement of existing standards. Based on a comparison of different approaches published in [8], only approaches consistent with the existing research will be included.

Finally, the calculation of fatigue life typically includes a binning of various operational states throughout the turbine life. This will be extended to include a calculation for all time steps, which reduces the uncertainty included by arbitrarily defined binning based on little to no objective guidelines.

The primary goals of these updates are to improve the result accuracy of the life calculation based on a limited number of tests and to include newer research results to obtain a calculation more consistent with the theoretical considerations on which ISO and ANSI/ABMA are based.

4 Raceway Wear

2009 DG03 contains several remarks on raceway wear which could not be confirmed by more recent research [13–15]. Wear on bearing raceways plays a minor to negligible role in operational failures. Boundary oscillation angles like the critical angle or dither are either not confirmed in real-scale tests or only play a minor role in operation. Several commercial greases show a high aptitude to prevent wear under adverse conditions [16, 17]. The DG03 update will reflect the current state of science and give advice on design, production, and operational strategies to prevent raceway wear.

5 Friction Torque

The 2009 DG03 suggests a simplified formula to calculate the running torque T of slewing bearings.

$$T = \mu \cdot \frac{d_m}{2}\left(\frac{4.4M}{d_m} + 2.2F_r + F_a\right) \qquad \textbf{Eq. 1}$$

where μ is the coefficient of friction; d_m is the pitch diameter of the bearing; and M, F_r and F_a are the moment, radial force, and axial force applied by the blade on the bearing. Friction torque measurements acquired from test rigs with only an applied bending moment do not coincide well with the results of the formula (see Figure 3) [18, 19]. Menck et al. [19] also show variations of more than 100% in running torque of bearings of the same type.

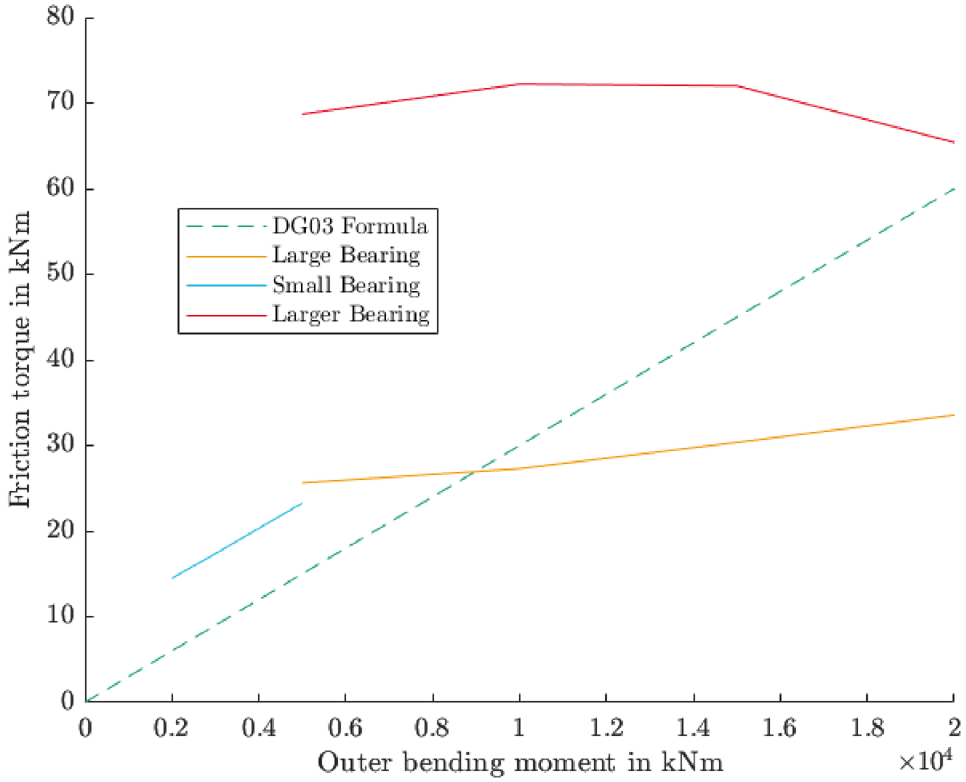

Figure 3: Comparison of DG03 running torque formula with measurement results

6 Conclusions

In 2023, NREL and IWES will update the pitch bearing design guideline DG03 from 2009. Several aspects like finite element modelling of pitch bearings, rolling contact fatigue calculations, wear considerations, and running torque will reflect the current state of science.

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