A Manual Process Sampling Solution for In-Service PAT Inspection of Wind Turbine Blade Bearing Lubricants

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ABSTRACT

Wind turbine failure is causing debilitating equipment/operational downtime and is always very costly due to the exceptional efforts required for repair or replacement – especially so for offshore turbines. Condition based monitoring (CBM) of grease lubricated turbine components (main and blade bearings) can greatly improve turbine reliability and reduce costs when properly applied. In-service monitoring of grease lubricated bearings is a win-win benefit at all levels. But is it possible to apply a PAT approach for in-service grease monitoring to develop a reliable warning system before breakdown? Alas, not directly - it turns out that certain necessary modifications to the standard PAT concept are needed. Here we present the development history of a manual process sampling solution for in-service PAT inspection and monitoring of grease lubricated main components in wind turbines.

1. Introduction

By demand for continuous operation 24/7/365, wind turbines can only operate with the necessary reliability if serviced by targeted condition monitoring of grease lubricated main components. This stringent demand is critically dependent upon reliable monitoring of the state of the grease in the bearings involved. Wind turbine grease lubricated bearings therefore need reliable monitoring, which must be as logistically easy as possible. For onshore wind turbines this is a fairly easy practical task (easy access), while for marine installations, offshore wind farms, this constitutes a significantly bigger logistical and engineering challenge (accessibility, weather, safety).

The task of inspection and monitoring both on-and offshore wind turbine grease lubricated bearings can be viewed under the general scope of Process Analytical Technology (PAT). Monitoring of a manufacturing/processing compositional component, or an active structural process component over time is usually a comparatively easy task provided there exists a relevant ´PAT sensor´able to interact with (in the present case) the in-situ grease located between the rollers and raceways of blade and main bearings in real time.

Preferentially a sensor yielding a multivariate spectral signal, which would allow a ´classic' spectroscopic PAT approach, calibrated and validated with chemometric models (Esbensen and Mortensen, 2010). Developing such a sensor would be truly revolutionary for the tribotechnology sector and its desire to offer the best, most efficient in-situ monitoring approaches.

Alas ... this has not been possible because of the overpowering practical difficulties involved in extracting either a spectral signal, or a physical sample from in-service grease lubricated bearings, far less a documentable representative signal/sample (sensu TOS).

The purpose of the present process sampling of in-service grease is to facilitate condition monitoring of the targeted bearings. The primary marker for any bearing's condition is the number, size, and morphology of wear debris in the active grease.

For these reasons the tribotech sector has for 15 years been involved in developing a manual alternative but with all the desirable benefits of PAT monitoring intact.

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The present authors have reported from this challenging journey at three LUBMAT conferences (Møller et al., 2012; Møller et al., 2014; Møller et al., 2016). Here we describe the objectives for this technological journey and summarise key findings and results. Our specific viewpoint is to develop an alternative manual process sampling solution for in-situ PAT inspection and monitoring of wind turbine grease lubricated bearings. The main thrust of the present article is to explain how, confronted with insurmountable obstacles for standard PAT, it has never-the-less been possible to find creative alternative engineering manual approaches obtaining the same solution benefits.

2. Summary of leading up history

This article presents the challenges and achievements over a period of 10+ years of developing an approach for representative sampling of grease from blade bearings based on the principles of the Theory of Sampling (TOS) (which is not necessarily a feature in current 'solutions') for condition assessment of blade bearings based on advanced grease analysis. Below, we focus on manual PAT monitoring of blade bearings. But first a brief introduction is provided of the main components of a modern offshore wind turbine.

An offshore wind turbine consists of the following main components, as shown in Fig. 1:

1. rotor blade assembly (hub and three blades)
2. nacelle
3. tower
4. transition piece

The rotor blade assembly comprises three blades, each with a bearing at its root. Blade bearings serve two purposes: i) connecting the blades (the unit that captures energy from the wind) to the nacelle; ii) enabling the blade to rotate around its longitudinal axis, i.e. to change its pitch (defining the wind attack angle with respect to the blade surface). For this reason, blade bearings are often alternatively termed 'pitch bearings', Fig. 2.

Since pitch bearings, by their nature, do not rotate continuously but only oscillate through a few degrees, conventional PAT-related monitoring methods such as vibration monitoring are not applicable. Therefore, the method described below is currently the best and most well-documented method for condition monitoring of blade bearings.

When a blade bearing has been assembled at a construction site, it is no longer possible to access its active part, i.e., the space between the outer and inner races to extract grease samples. However, in operation there is a continuous supply of new grease to the bearing, while the excess grease is pressed out and collected in containers located on either the outer or inner race of the blade bearing. These containers are accessible for extracting in-service samples, Fig. 3.

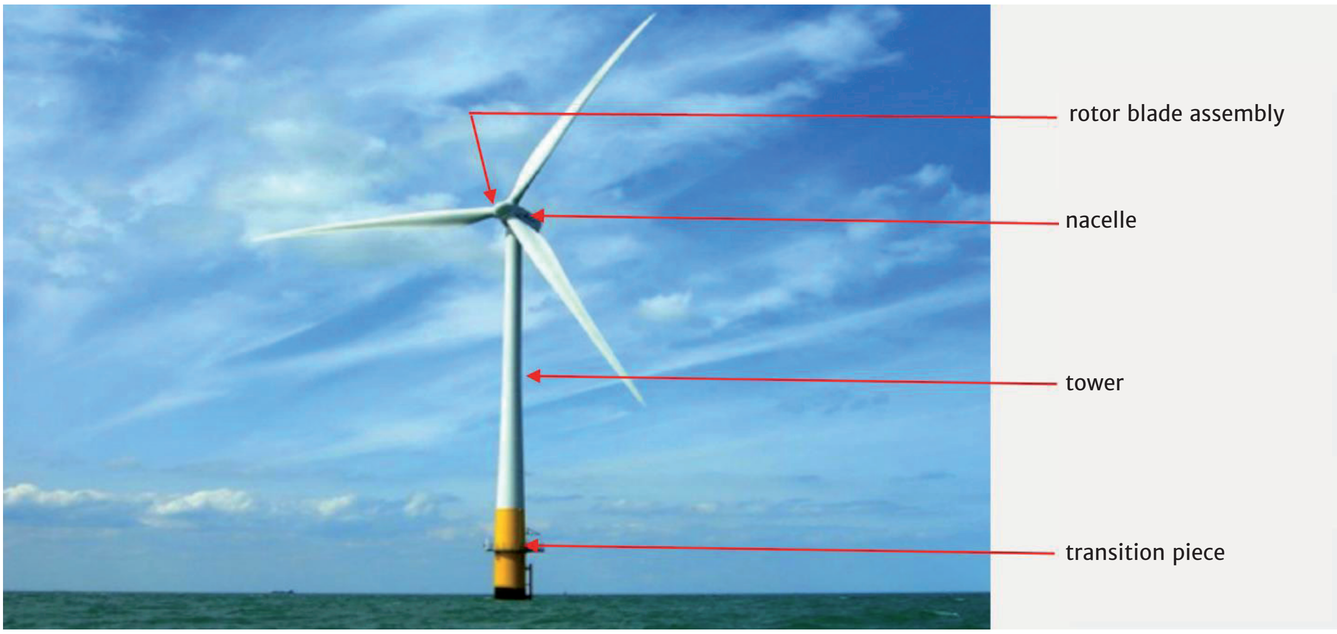

Figure 1: Main structural components of an offshore wind turbine.

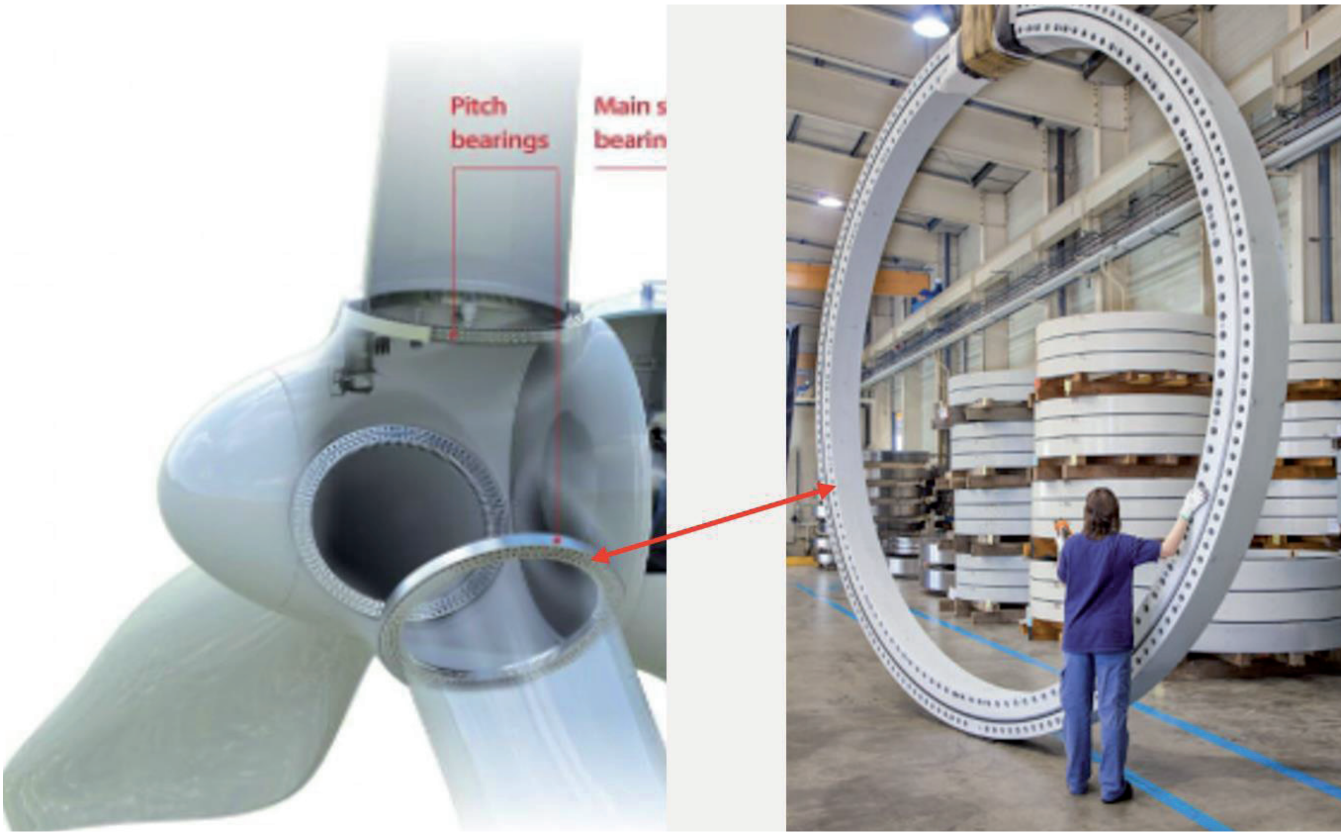

Figure 2: Rotor blade assembly (left) and a blade (=pitch) bearing (right). Note the raceway between the outer and inner races, from where samples of the active grease shall be extracted.

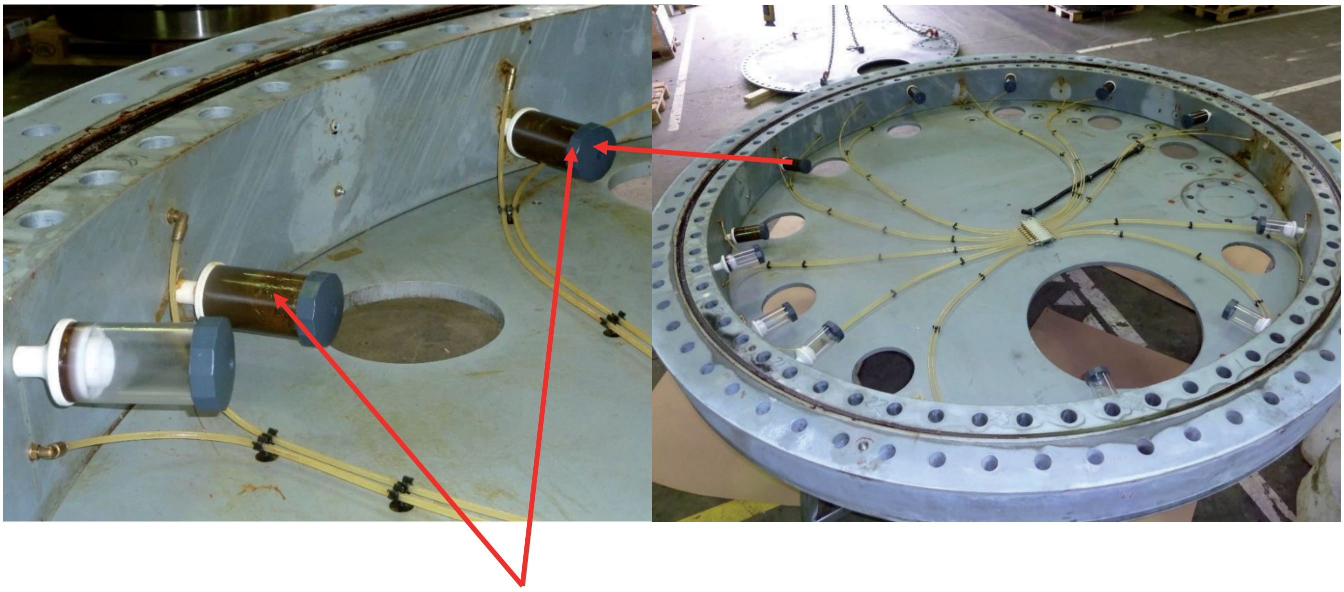

Figure 3: Blade bearing in a 3.6 MW turbine with grease collecting devices ("Grease cups") fitted to the inner ring. These grease cups are accessible for sampling of in-service grease samples used for condition monitoring, see Figure 5.

For calibration of the present new sampling approach, it was possible to carry out a comprehensive 3-D heterogeneity characterization of the grease in the 360 deg active zone of blade bearings; this was reported in an earlier study (Møller et al., 2016). A summary will suffice for the present purpose.

With a bearing dismantled for onshore inspection, it was possible to conduct sampling of the active raceway in a representative fashion in full compliance with TOS, as illustrated in Fig. 4. Dismantling allows sampling and full characterization of the variation and properties of the grease along the full 360-degree active zone of the bearing in the space between the raceways. This sampling scheme, here termed the 3-D heterogeneity characterization, forms the reference against which the in-service grease cup sampling can be compared and evaluated.

From a TOS point of view, the in-service grease cup sampling, and analysis (performed in the analytical laboratory) is fit-for-purpose representative (Esbensen and Mortensen, 2010); therefore, it is the best available proxy for direct characterization of the properties of the active raceway grease - be this in the form of an average over the full circumference, or as a mapping of the peripheral compositional variation in the active zone between the raceways (Møller et al., 2016).

The analytes used in the reference characterization were i) content of ferro-magnetic iron, ii) water content, and iii) particle size distribution of wear debris.

In total 175 grease samples were included in this comprehensive reference study.

2.1 In-service, in-situ condition monitoring

Blade bearings have an atypical mode of operation, as they do not normally rotate when the turbine is in operation. This means that traditional, highly successful vibration analysis is not an option. Physical sampling (and analysis) of grease from the active blade bearings is therefore the only useful method for obtaining reliable data for assessment of current operating conditions. The most important analytes for this purpose is the content of wear particles, their size distribution and their morphology. Dedicated laboratory procedures have been developed, which have proven to be suitable for this purpose. It is the experience that only wear particles larger than ~100 µm are relevant for a condition check of blade bearings (Møller et al., 2012, Møller et al., 2014, Møller et al., 2016).

2.2 Grease cup samples - a match to PAT process samples

As a rule, during inspection visits to active offshore windmill nacelles, which takes place for other monitoring purposes as well, grease extraction is also routinely performed from two randomly selected grease cups along the complete inner raceway of a given bearing, Figs. 3,5. These samples form bona fide PAT samples extracted from the process.

Figure 4: Representative reference grease sampling from a dismantled 3.6 MW blade bearing. Increments from every second ball support hole were used for 3-D heterogeneity characterization of the grease in the complete 360 degree active zone in the space between the raceways. This is a 1-to-1 match analogue to "stopped belt" sampling in conventional PAT.

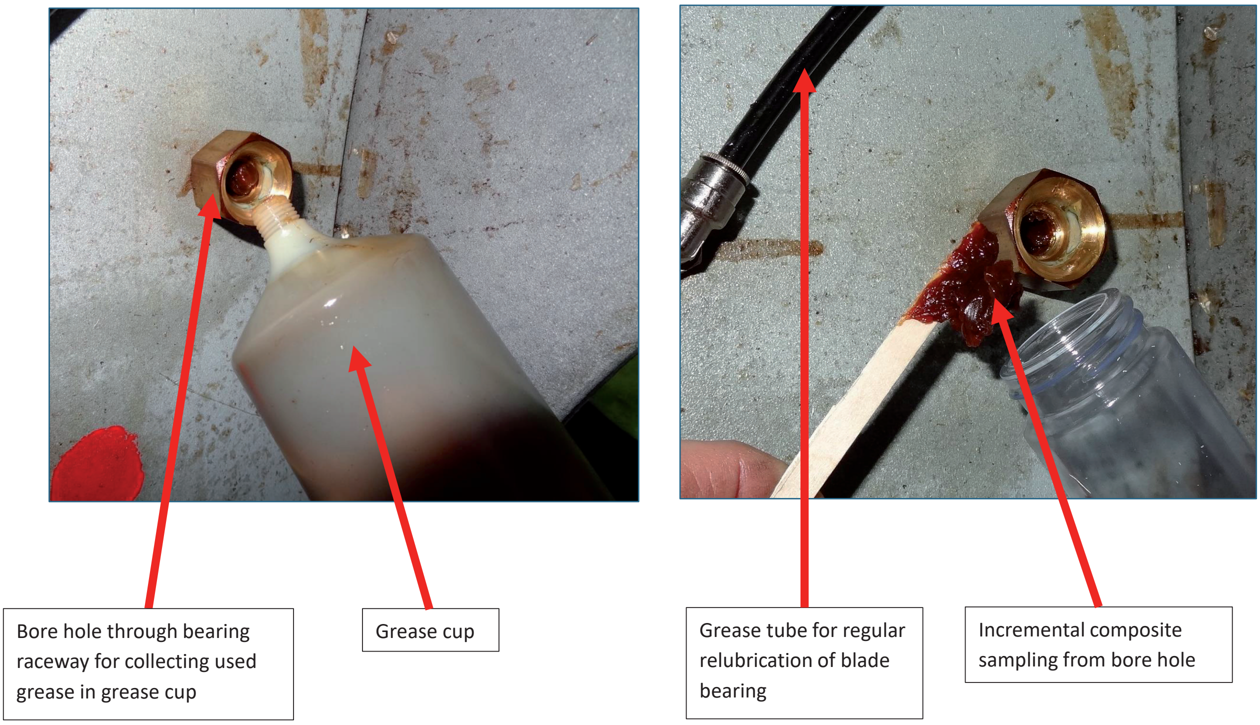

Figure 5: Manual PAT at work in the Baltic Sea. Inspection and monitoring crew visiting the nacelle of windmill Rødby 2, Baltic Sea is extracting composite samples from grease cups holding used blade bearing grease (see also Fig. 3).

We refer to (Møller et al., 2016) for technical description of three case histories documenting the calibrating comparison between the reference and the present grease cup sampling. Here it was demonstrated how this approach can accurately determine the physical condition of the targeted bearings. These comprehensive results led to the conclusion that 'grease cup' sampling is a satisfactory proxy for representative sampling from an active raceway.

3. Discussion

Based on the Theory of Sampling (TOS), it has been possible to develop an alternative method for acquiring representative samples of active grease from blade bearings in offshore wind turbines. This is a crucial prerequisite for development of a practical, economically reasonable and logistically operational condition monitoring approach of in-service blade bearings. The new method has been compared and evaluated to a comprehensive, fully TOS-compliant refence sampling performed on dismantled bearings; this reference sampling is a direct analogue to 'stopped belt' reference sampling in the conventional PAT context, allowing realistic calibration and evaluation.

4. Conclusions

It has been possible to develop a fully validated manual process sampling solution for PAT in-situ inspection of wind turbine bearing grease. This is the only possible approach for Condition Monitoring of in-operation wind turbines.

5. Perspective

Globally, in many countries, offshore wind turbines are becoming an increasing part of the technical backbone for the necessary transition to a CO_2- free renewable energy supply. Offshore wind turbines are extremely capital-intensive investments, for which reason cost-effective methods for operating and monitoring these assets are highly desirable. To solve this task, many different analytical tools (physical, chemical, AI) are used today to process today's readily available on-line data remotely onshore (with obvious needs for automation).

However, there are still main components, for which no documented method for continuous operational monitoring exists – yet. To monitor the state of the crucial blade bearing components, the authors consider regular in-service physical PAT sampling and analysis of bearing grease to be the most suitable method available today.

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