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E-Futures

Mini-project report

HIGH RELIABILITY AND LOW FRICTION BEARINGS FOR WIND TURBINES

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Date: 11/02/2010

Research Councils UK Energy For a Low Carbon Future

Abstract - The need for affordable and reliable wind turbines is now very important as the world shifts its energy focus to renewable sources. Wind turbine failure statistics show that most of the operating downtime is bearing related. This project therefore, looked at the various bearing options available to the different bearing components of a wind turbine.

1. INTRODUCTION

The bearings are a vital part of wind turbines. They have to operate continuously under varying load and frequently intermittent lubrication. Offshore wind farms are also difficult to maintain and re-lubrication is expensive. Currently very large rolling element bearings are used. There have been several catastrophic failures caused by bearing failures which has resulted in huge downtime, **Fig.1**, in the operation of wind turbines.

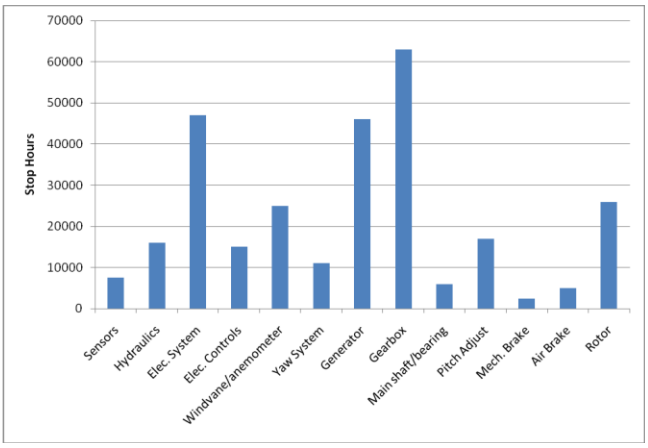

Fig. 1 Downtime hours accumulated from 2003 to 2007 for wind turbines operating in Germany[1]

Various propositions have been made to resolve this problem as it is expected that a wind turbine bearing should have a minimum life cycle of 20years[2]. Options range from an entire change of the wind turbine architecture, use of different bearings to material enhancements (surface coating, bearings materials and oil additives). This project will investigate alternative designs for wind turbine bearings with focus on the conventional turbine bearing architecture.

2. APPROACH TO PROJECT

The comparative analysis approach was adopted for this study[3]. Comparisons were made between the bearings capable of functioning within the constraints at which wind turbines operate. This approach conforms to the standard principles of bearing selection for mechanical devices. First and foremost the design constraints where analysed and compared with the bearing selection matrix of bearing manufacturers for bearing options which are further analysed using life field data from a wind farm. The basic bearing life calculation was the ultimate deciding factor on which comparisons were made for the different bearings within the turbine.

3. WIND TURBINE ARCHITECTURE

Fig.2 shows the typical structure of a modular wind turbine. It consists of three main parts, the tower, a three bladed rotor and the nacelle. Bearings, which are machine components that allow the positioning of one part with respect to another in such a way that relative motion is possible, come into play in various parts of the turbine. The nacelle and the tower are connected via a yaw system, which includes either a rolling element bearing or a sliding bearing to allow the positioning of the blades in the direction of the wind. Also, the blades are attached to the hub via a pitch bearing to enable easy adjustment to suit various wind situations.

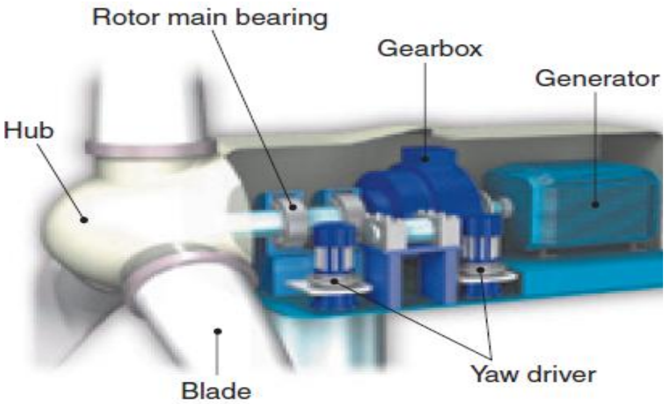

Fig. 2 Nacelle [2]

The nacelle is composed of the main shaft, the gearbox and the generator. For effective transmission of the rotation to the gearbox, the main shaft is held into place by main shaft bearings. The gearbox is a collection of gears arranged to increase the speed received from the main shaft with the aid of bearings.

4. BEARING SELECTION

The reliability of the bearing throughout its design life and cost effectiveness are the benchmark for selection. Hence the proper type and size of bearing must be selected. The selection process must consider all factors which will affect bearing performance and cost.

These factors include: Magnitude and direction of loads, speed of rotation, required life, available space, lubrication, shaft and housing designs, alignment, adjustment, temperature and environment. As a foundation project, the magnitude and direction of load, including the speed of rotation, required life and available space have been considered the critical factors.

4.1 Bearing life calculation

It is expected that wind turbines operate for 175,000 hours (20years)[2]. The basic life calculation formula was used for this project, which involves the steps below;

1. Get the dynamic basic load rating for the bearing from manufacturer's catalogue
2. Calculate the dynamic equivalent load; and
3. Using the values to calculate the bearing life.

$$L_{10} = \frac{10^6}{60n}\left(\frac{C}{P}\right)^p$$

n: rotating speed[min^{-1}]
C: basic load rating [N]
P: dynamic equivalent load [N]
p: p = 3 for ball bearing, p = $10/3$ for roller bearing

Dynamic Equivalent Radial & Axial Load

$$P_{er} = XF_r + YF_a$$

$$P_{ea} = 0.75F_r + F_a + \frac{2M}{d_m}$$

$$P_m = \left(\frac{\sum P_{ei}^p n_i t_i}{\sum n_i t_i}\right)^{1/p}$$

P = equivalent dynamic bearing load [kN]
F_r = actual radial bearing load [kN]
F_a = actual axial bearing load [kN]
X = radial load factor for the bearing
Y = axial load factor for the bearing

5. MAIN SHAFT BEARING

Fig. 3 illustrates the load analysis acting on the main shaft. The loads acting on the main shaft are in the form of a radial load from the mass F_{ZN}; a side load from the wind F_{YN}; and rotor thrust F_{XN} and over turning moments from the blades in the two planes. The load data used for this analysis is from a binned load cycle with over 500 variable loads for an 8MW turbine. An assumption has been made for the rotating shaft speed as 16rpm and the shaft diameter as 900mm. The side load from the wind F_{YN} has been ignored since it is negligible when compared to F_{ZN}.

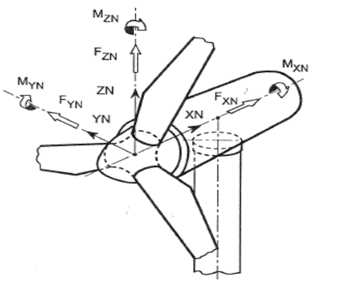

Fig. 3 Loads & Working System of Axis[3]

The main shaft consist of two bearing locations – the fixed bearing, which is located close to the blade, and the floating bearing situated close to the gearbox. The table below show the calculated bearing life of the two points.

Table 1. Main Shaft Fixed Bearing Analysis

Bearing Type		P_m *kN*	C *kN*	L_{10} *Mrev*	L_{10} *hr*
TRB	SR	666.54	3960	379.80	395625
	DR	1281.95	16800	5306.33	5.52E6
SRB		1281.95	21400	11888.92	12.38E6
ABB	SR	211.98	1560	398.55	0.42E6
	DR	553.00	676	1.82	1895.83

Table 2. Main Shaft Floating Bearing Analysis

Bearing Type		P_m *kN*	C *kN*	L_{10} *Mrev*	L_{10} *hr*
ABB	SR	342.69	1330	58.45	6.09×10^4
SRB		1281.95	18400	7204.74	7.5×10^6
CRB	SR	120.21	7040	780022.02	8.12×10^8
	DR		16500	133880421	1.33×10^{14}
	4R		19800	4495255.68	4.5×10^{12}
TRB	SR	666.54	11000	5.311	5.53×10^3
	DR	762.60	14700	19204	2×10^7

6. YAW BEARING

Thrust load is the most important factor for the yaw bearing as it rotates the nacelle. It rotates at a low and constant speed. A constant speed of 0.285rpm and size of 1400mm has been used for this analysis. Table 3, shows the bearings analysed and their respective bearing lives.

Table 3. Yaw Bearing Analysis

Bearing Type		P_m *kN*	C *kN*	L_{10} *Mrev*	L_{10} *hr*
TCRB		543.7	1587	35.54	2.08×10^{6}
TSRB		470.70	36800	$2.04\text{x}10^{6}$	1.19×10^{11}
ABB		532.85	1460	20.57	1.2×10^{6}
BB	SR	529.09	1900	46.31	2.71×10^{6}
TTRB		481.30	3300	612.33	3.58×10^{7}

7. PITCH BEARING

The bearings experience a higher axial load as the blades swing round compared to the occasional radial load experienced as it rotates to captures the air streams.

Table 4. Pitch Bearing Analysis

Bearing Types	P_m *kN*	C *kN*	L_{10} *Mrev*	L_{10} *hr*
TTRB	1111.16	3580	49.40×10^{6}	3.92×10^{4}
TSRB	1015.16	9550	17.57×10^{8}	1.39×10^{4}
TRB- SR	1194.55	1470	1.92×10^{6}	1.52×10^{3}
SRB	1004	9300	1.66×10^{6}	1.32×10^{3}
4P-ABB	997.29	1680	5.69×10^{6}	4.52×10^{3}

8. GEAR BEARING

The table below consist of a list of possible bearings for the various rotating areas of the gearbox. As a result of lack of data, only the first analysis was carried out for the gearbox that is comparing the qualities with the manufacturer's selection matrix. The factors include high speed and radial loading.

Table 5. Bearing Type for Gearbox[2]

Area		Bearing type
High-speed shaft	Fixed-side	SRB, CRB, TRB, BB, 4PCBB
	Free-side	SRB, CRB, BB
Intermediate shaft	Fixed-side	SRB, CRB, TRB, 4PCBB
	Free-side	SRB, CRB
Low-speed shaft	Fixed-side	SRB, TRB
	Free-side	SRB, CRB, FCCRB
Planetary gear		SRB, CRB, FCCRB, TRB
Carrier		FCCRB, SRB, TRB

SRB: Self-aligning Roller Bearing CRB: Cylindrical Roller Bearing
FCCRB: Full Complement Cylindrical Roller Bearing TRB: Tapered Roller Bearing
BB: Deep Groove Ball Bearing 4PCVBB: Four Point Contact Ball Bearing

9. RESULTS

At the moment, the main shaft uses an SRB on both bearing points. Though the SRB calculated bearing life in this project is higher than the other bearings of interest, the TRB - SR /DR or ABB – SR nevertheless exceeds the 20 years desired operation life of a wind turbine for the fixed end. Similarly at the floating end, the CRB – SR/DR/4R, TRB – SR/DR and ABB – SR have lower bearing life compared to the SRB but exceeds the 175000hrs threshold. It is therefore safe to say that proper combination of either TRB - SR /DR or ABB – SR at the fixed end with anyone of CRB – SR/DR/4R, TRB – SR/DR and ABB – SR at the floating end offers alternatives, taking into account the recurrent failures experienced using the SRB and also that this project has not taken into consideration other design factors.

Likewise, the CRB is currently in used for the yaw bearing and has options of TCRB, TSRB, ABB, BB and TTRB. The pitch bearing utilises the eight point ball bearing amongst other types. The result of the pitch bearing shows none of the selected bearing matches the desired life. However, this can be due to several factors as the calculation is purely based on the manufacturers design.

10. CONCLUSION

Proper bearing design and application is the key to reducing downtime and maintenance cost. Special bearing designs for wind turbines as opposed to standard bearing design should be the focus.

11. REFERENCES

[1] F. Oyague and N. R. E. Laboratory, *Gearbox modeling and load simulation of a baseline 750-kW wind turbine using state-of-the-art simulation codes*: National Renewable Energy Laboratory, 2009.

[2] S. Y. a. N. Ninoyu, "Technical Trends in Wind Turbine Bearings."

[3] L. I. a. T. Pontius, "Main Shaft Support For Wind Turbine With A Fixed And Floating Bearing Configuration."

[4] M. Neale, *The tribology handbook*: Butterworth-Heinemann, 1995.

[5] J. Shigley, *et al.*, *Mechanical engineering design* vol. 5: McGraw-Hill New York, 1989.

NOMENCLATURE

4P-ABB	Four Point Ball Bearing
4R	Four Row
ABB	Angular Ball Bearing
BB	Ball Bearing
CRB	Cylindrical roller Bearing
DR	Double Row
SRB	Spherical Roller Bearing
TRB	Tapered Roller Bearing
TSRB	Thrust Spherical roller bearing
TTRB	Thrust Tapered Roller Bearing