Wind Turbine Main Bearing Rating Lives as Determined by IEC 61400-1 and ISO 281

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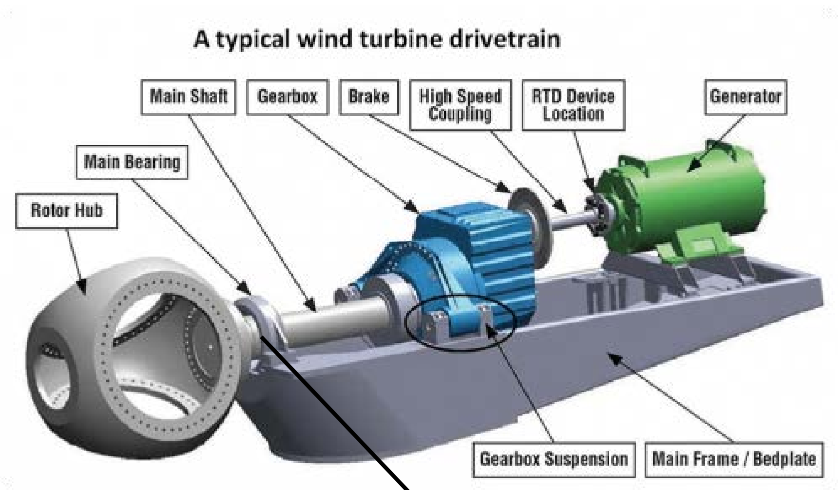
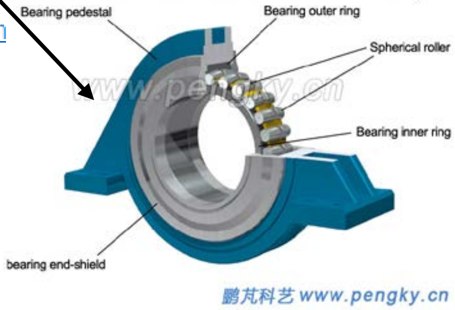
Introduction

- Wind turbine main bearing rating lives are determined using ISO 281 and ISO/TS 16281 and are required by IEC 61400-1 to meet or exceed the design life of the wind turbine.
- **Field data show 22–25% failure rate at year 20.**[1]
- Wind turbine main bearing failures represent a significant cost to the operators.



https://www.windpowerengineering.com



1. Edward Hart, Kaiya Raby et al. 2023. *Main Bearing Replacement and Damage – A Field Data Study on 15GW of Wind Energy Capacity.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-86228. http://www.nrel.gov/docs/fy23osti/86228.pdf.

Introduction

- Is rolling contact fatigue a principal driver of premature failures of main bearings?
- Anecdotal consensus indicates perhaps not.
- Few studies exist in which comprehensive, transparent assessments of main bearing rating lives are undertaken.

Research question

- *Can the rating life assessment, as codified in the IEC 61400-1 and ISO 281 standards, account for the reported premature failure rates of 1–3 MW wind turbine main bearings?*

Basic Rating Life – value of bearing life 90% of the population of bearings that are expected to attain or exceed

Given by bearing manufacturers

From pre-1940s fitted experimental data (Palmgren Lundberg bearing life model) - $(p = 10/3)$

$$L_{10} = \left(\frac{C_D}{P_{eq}}\right)^p$$

Calculated during rating life assessment

L_{10} - basic rating life (millions of revolutions)

C_D - dynamic load capacity/rating (load at which L_{10} = 1 million revolutions)

$P_{eq} = XF_r + YF_a$ - equivalent applied bearing load

p - load life exponent

- In 1947 Palmgren devised a probabilistic approach to rolling bearing reliability.
- Palmgren and Lundberg parametrized their bearing life model with pre-1940s experimental bearing life data
- Their fitted coefficients are still the basis of the ISO rating life formulae used today.

Modified Life Rating – incorpoates lubricant temperature-viscosity, contamination, and the bearing fatigue-load limit

$$L_{nm} = a_1 a_{ISO} L_{10}$$

a_1 - modify the survivability of the population
a_{ISO} - modify the basic life rating

$$a_{ISO} = f\left(\frac{e_C C_u}{P_{eq}}, \frac{\nu}{\nu_1}\right)$$

C_u - accounts for the fatigue load limit of the bearing (applied load below which bearing will not fatigue)
e_C - accounts for the level of contamination
ν/ν_1 - accounts for the effect of lubrication regime

All: calculated using formulae in ISO 281

$$\sum_n \frac{m_n}{L_{nm}} = 1$$

Linear damage accumulation assumption (Palmgren-Miner)
$\frac{m_n}{L_{nm}}$ - proportional damage associated with time spent at operating state n

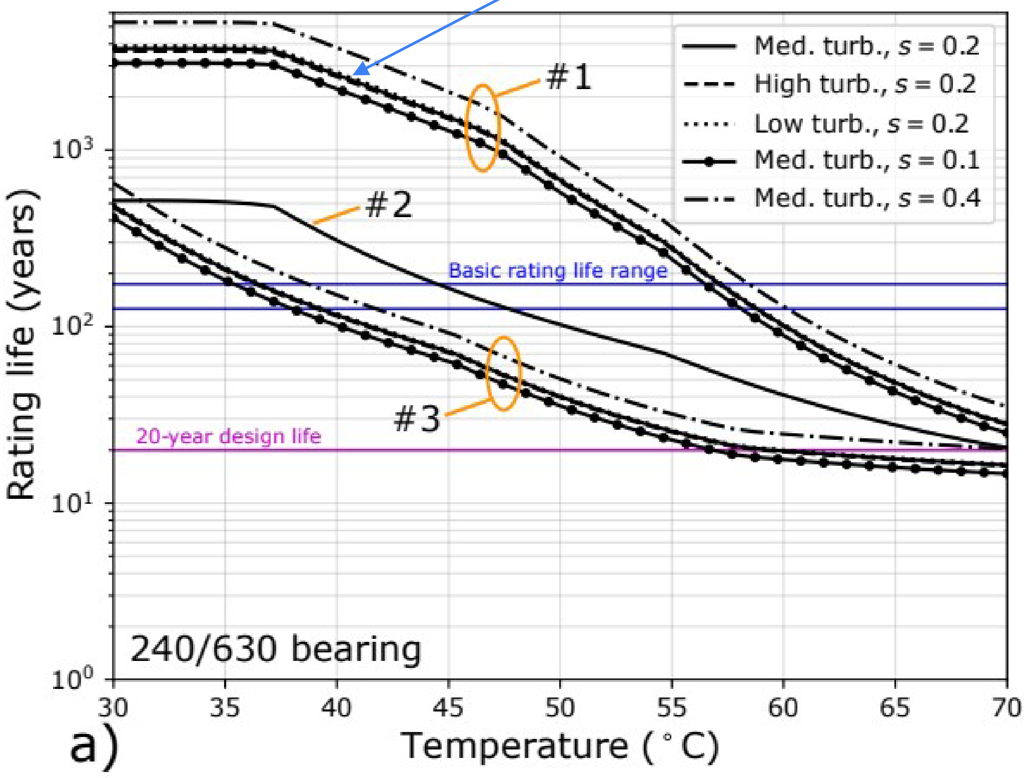
Methodology

1. ISO 61400-1 - wind turbine design requirements - calculate hub loads across a range of mean wind characteristics using an aeroelastic simulation model
   a) Wind speed (2–24 m/s): **shear exponent (0.1, 0.2, 0.4) and turbulence class (low, medium, high)**
2. Calculate equivalent applied bearing load from bearing reaction forces using static force balance model
3. Choose bearing: **240/630 – higher dynamic capacity (P_{eq}) and fatigue load limit (C_u), 230/600 – lower dynamic capacity (P_{eq}) and fatigue load limit (C_u)**
4. Calculate L_{10m} using ISO 281 – varying viscosity ratio (ν/ν_1) through temperature and contamination level through contamination factor (e_C)
   1) **viscosity 30°–70°C (460-16 $\mathrm{mm^2 s^{-1}}$); low contamination**
   2) **viscosity 30°–70°C (460-16 $\mathrm{mm^2 s^{-1}}$); high contamination**
   3) **viscosity 30°–70°C (330-8 $\mathrm{mm^2 s^{-1}}$) (as per [1]); high contamination**

[1] Yucesan, Y.A. and Viana, F., 2019. Onshore wind turbine main bearing reliability and its implications in fleet management. In *AIAA Scitech 2019 Forum* (p. 1225).

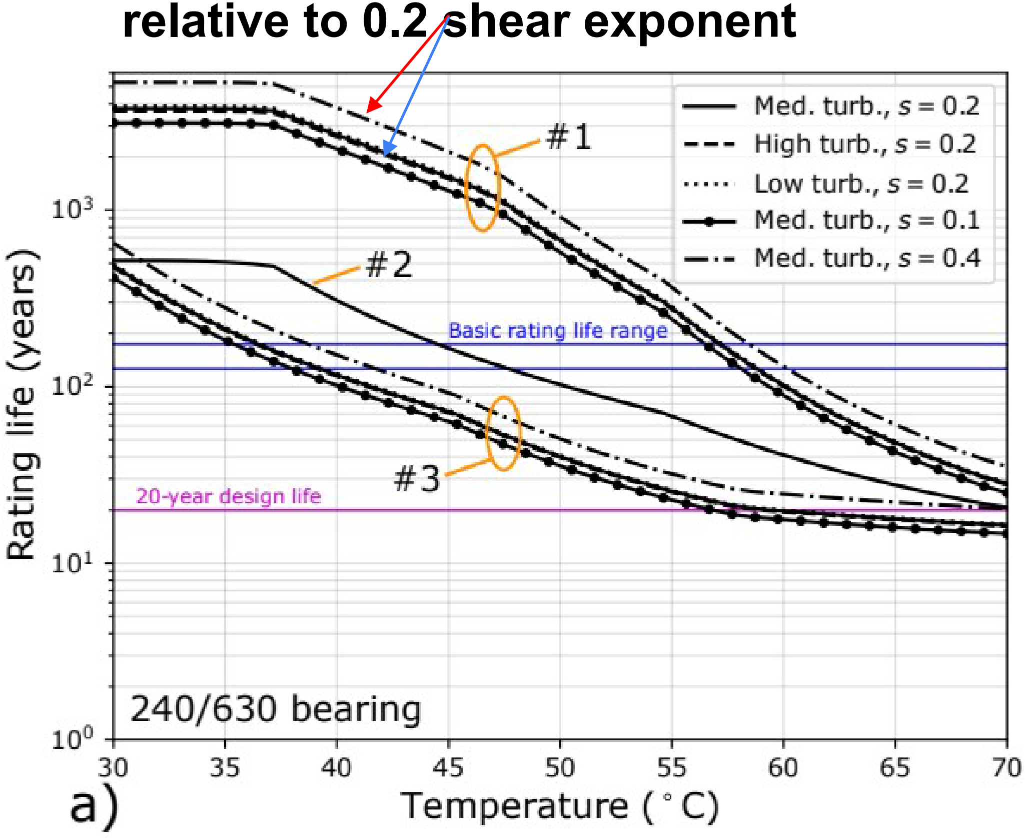
Results

1. Turbulence intensity weakly affects rating life



Results

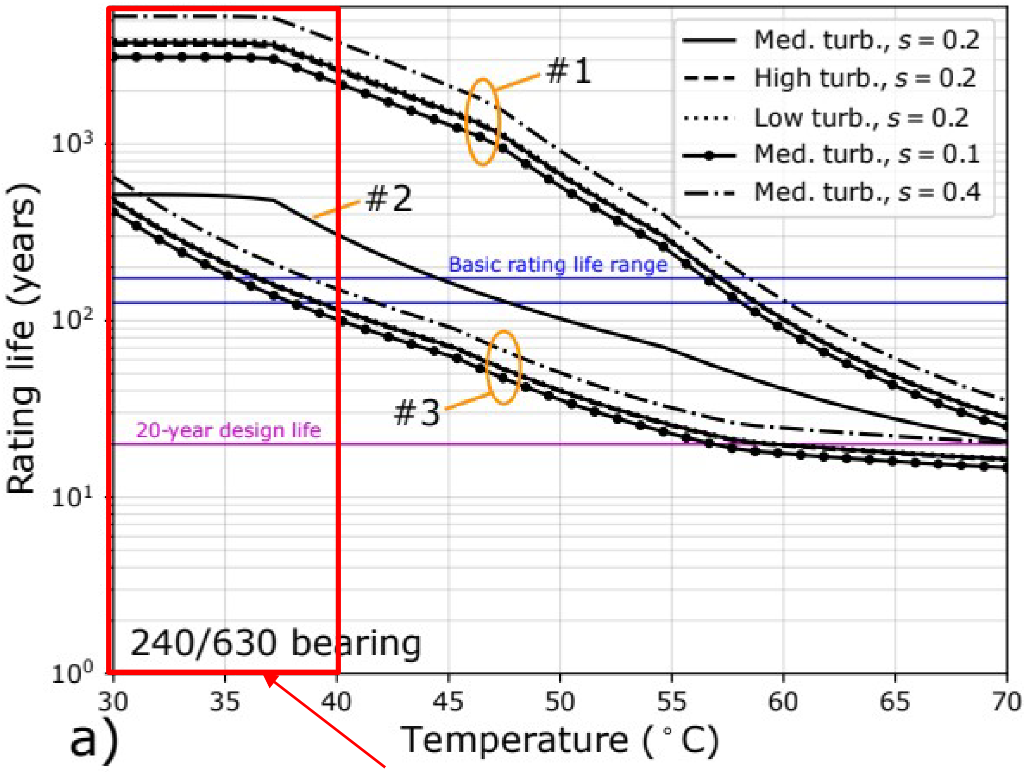
2. Shear exponent 0.4 increases rating life, shear exponent 0.1 decreases rating life relative to 0.2 shear exponent



Results

3. Temperature/viscosity and contamination are main drivers of main bearing rating life

$$a_{ISO} = f\left(\frac{e_C C_u}{P_{eq}}, \frac{\nu}{\nu_1}\right)$$



Typical wind turbine main bearing temperature operating range

1: viscosity 30°–70°C ($460\text{-}16\ \mathrm{mm^2 s^{-1}}$)
Low contamination

#2: viscosity 30°–70°C ($460\text{-}16\ \mathrm{mm^2 s^{-1}}$)
High contamination

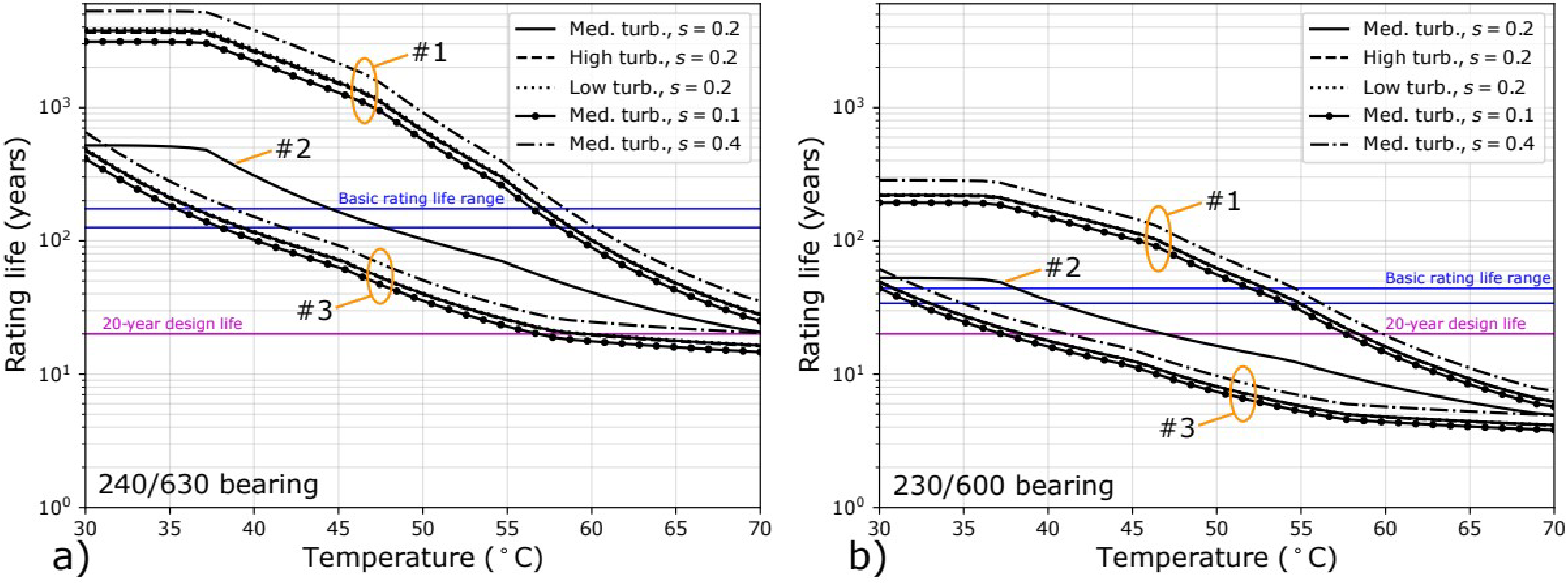
3: viscosity 30°–70°C ($330\text{-}8\ \mathrm{mm^2 s^{-1}}$)
High contamination

Results

4. Bearing type/fatigue load limit C_u affects rating life

240/630 - $C_u = 1141$
230/600 - $C_u = 750$

$$a_{ISO} = f\left(\frac{e_C C_u}{P_{eq}}, \frac{\nu}{\nu_1}\right)$$



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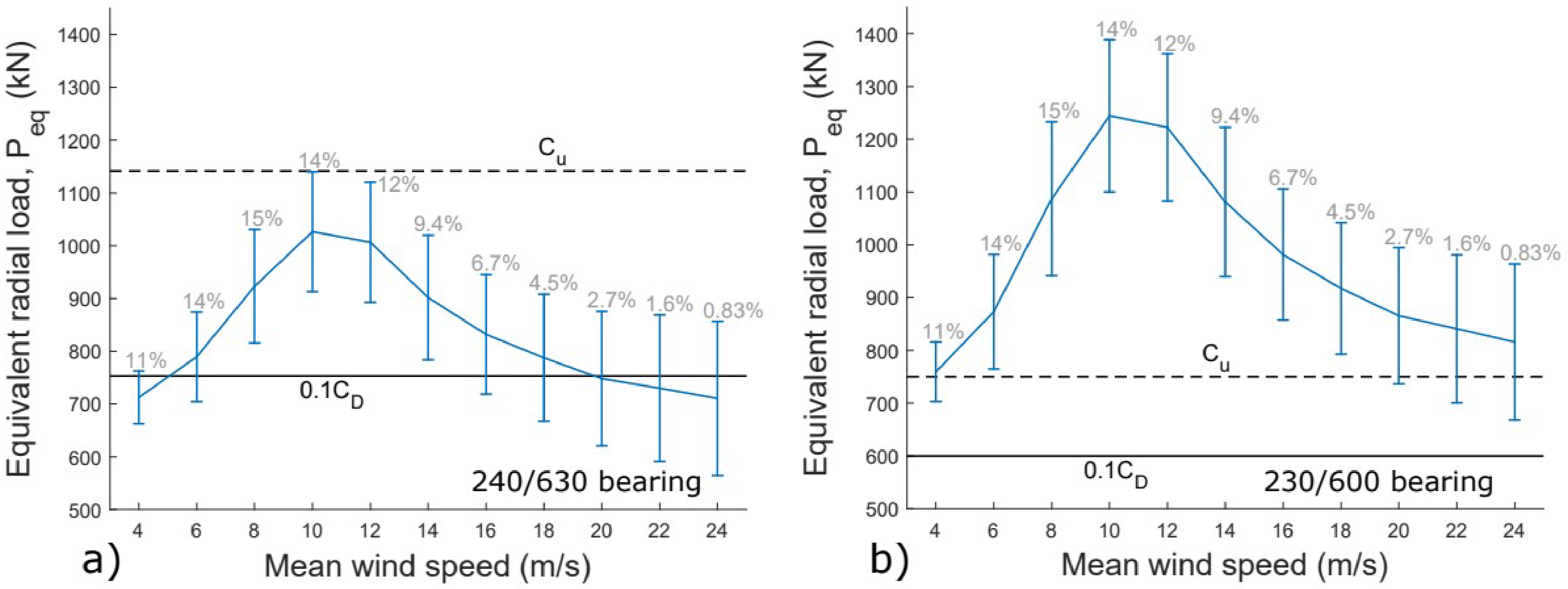

Conclusions

- This work has studied the rating lives of wind turbine main bearings as determined by IEC 61400-1 and ISO 281.
- Assumptions of the ISO 281 standard were outlined: in particular, the fatigue load limit and assumption of linear damage accumulation.
- Rating lives were found to be sufficiently above a 20-year design life for expected operating temperature and grease contamination conditions.
- Rating life assessment is unlikely to account for the reported rates of main bearing failures in 1 to 3 MW wind turbines.

Questions

Full details will be made available in a paper, which is currently under review

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