Wind Energ. Sci. Discuss.,
https://doi.org/10.5194/wes-2020-58-AC2, 2020

WESD

Interactive comment

Interactive comment on "Constructing Fast and Representative Analytical Models of Wind Turbine Main-Bearings" *by* James Stirling et al.

James Stirling et al.

j.stirling@strath.ac.uk

Received and published: 27 August 2020

Dear Reviewer,

Thank you for taking the time to study this paper and provide valuable constructive criticism which we believe has helped develop and strengthen this work. I have laid out all of your comments below and responded each of them in turn (in blue). Some comments touch upon the overall goal of this work and so the opening of the response has been written to clarify the main goals and overall narrative of the paper. Having received feedback on the paper we now realise that this was not outlined clearly enough in the original manuscript and so we will also be making this clearer in the updated paper.

Printer-friendly version

Discussion paper

If more information is required or we have misinterpreted any of your comments, then please don't hesitate to get in contact and we will be happy to provide extra information to remedy this.

Best regards,

James Stirling (Lead author)

Review Comments and Author Response

Opening:

Recent work which has demonstrated important and unusual load behaviours in wind turbine main bearings has used simplified analytical representations of the drivetrain. Such simple representations will be necessary if this type of analysis is to be performed for large numbers of load cases, incorporated into fleet wide wind turbine digital twin models, used in wind farm simulation software or as part of industry standard BEM programs such as Bladed or FAST. Analytical models of these type are therefore important and already utilised in some instances. However, to date a detailed assessment of how effectively these models represent wind turbine drivetrain load reaction at the main bearing (including different bearing types) has not yet been carried out and it is therefore important to scrutinise the validity of these models and where they might apply.

Wind turbine drivetrains and main bearings in particular are specific to individual turbine designs, as such we are looking to understand in as much generality as possible how these types of analytical models may be used to represent main bearing load characteristics, without focussing on any one design case (since this would reduce the generality and applicability of results). In order to move in this direction, we have identified a need to work up through the available levels of complexity of modelling, understanding at each stage how one model represents the next in the chain. The benefit of such an approach being that at each stage, whenever a lack of agreement is found (such as in the TRB case of the present paper) small additions to the model can be sought to bring the quality of outputs back towards something which is accurate enough to be useful, while also developing knowledge about which effects can and can't be captured at each level.

In the current paper we are starting with the existing 2-dimensional, orthogonally independent, simply supported models and looking to compare with something closer to representing a real world main bearing in a wind turbine drivetrain. Since the strongest assumptions in the initial models are independence of horizontal and vertical planes (from a load perspective) and simply supported load reactions (no moment reaction, only force), we wish to compare their performance against more realistic models that don't necessarily make these assumptions. A 3-dimensional FE model avoids the orthogonality assumption. With respect to simple vs other support types we want to give the 3D model force reaction capabilities which are closer to those of real main bearings in order to assess when the simple support assumption is valid (and to consider how the simple model might be extended to compensate when it's not valid). Main bearings for wind turbines are known to have two force reaction 'types' in general. Bearings that support forces only and not moments (double row SRBs), and bearings that support both forces and moments (double row TRBs) and so simplified bearing representations are created for the 3D FE model which have these general support behaviours (without being exact models for a specific bearings).

Hence, the overarching research goal of this paper is to answer: Can analytical models be used to effectively evaluate load reaction behaviours for 3-dimensional support configurations with either moment reacting or non-moment reacting behaviours at the main support point? Tackling this question in the current paper demonstrates the validity of existing models for force reactions on the bearing as a 'unit' while also setting the stage for further work with more detailed analytical and FE model comparisons which, for example, could start evaluating internal load distributions etc.

Review comment:

Specific comments: To be repeatable, basic parameters such as bearing dimensions and stiffnesses should be given. This is not consistently done in the manuscript

Response:

Some parameters were initially left out of the paper due to commercial sensitivity. However, we agree that the inclusion of such parameters will help strengthen the paper by increasing repeatability and have spoken to industry partners who have given the go ahead to disclose such information in the updated manuscript. A table has also been included to the paper which provides specific input forces and output results for all of the models to help the reader to gain an understanding of the behaviour of the models and to aid in repeatability.

Review comment:

In general, more detailed illustrations of the FE models would clearly contribute to understanding. In particular, the consideration of the contact conditions and their simplification within the FE-models should be considered in detail

Response:

We agree that the reader's understanding of the work and the FE models would be greatly improved by the inclusion of more detailed illustrations of the FE models and these will be included in the updated manuscript. We also feel the paper would be improved through a more detailed description of the FE models and have, therefore, included information giving all dimensions, details of the mesh and how the mesh was obtained, connection types and contact conditions in the updated manuscript. This will not only help the reader to better understand the work undertaken but will also improve reproducibility.

Review comment:

The elastic behaviour of the bed plate is set rigid. The author should indicate how this simplification affects the results

Response:

We have looked at the relevant literature (e.g., [1]) concerning modelling of the bed-plate and agree that the assumptions made in this study should be brought to the reader's attention and we will therefore include a discussion of this point in the updated manuscript.

Review comment:

The physical modelling of the main bearings is not comprehensible. It seems that the spherical roller bearing has been replaced by a deformable spherical joint. It remains questionable whether this form of modelling is permissible, since the contact conditions between rolling elements and running surfaces, which varies under load, results in the characteristic non-linear stiffness of the bearing as such. In addition, no statement is made to whether the bearing clearance of the spherical roller bearing is taken into account. It is unclear how the mesh has been obtained. It is said that larger elements are used for the shaft and smaller elements are used around the bearing and bearing housing to increase accuracy at the contact regions. The mesh density is normally obtained by a convergence study. The author should indicate if this was carried out here

Response:

The purpose of this paper was to develop fast and representative models that can accurately capture the different behaviours between generic SRB and TRB load reaction behaviours when subjected to complex wind loading. As the study was designed to capture general bearing unit force reactions and not internal loads, the SRB was replaced by a deformable spherical joint. The spherical joint in ANSYS will allow the

Printer-friendly version

Discussion paper

bearing housing to deformably react forces in the X, Y and Z axes while being able to move freely in the rotational degrees of freedom. This allows the non-moment reacting behaviour of an SRB to be captured in a 3-dimensional model without going into the complexity of modelling individual rollers and hence, the global behaviour is still captured in this model in a general form. The characteristics of this simplification and the implications of it in the modelling will be discussed in the revised manuscript.

Referring back to the opening of the response, the overall goal of this study was to determine if the models in the previous study can accurately represent 3D equivalents. Although internal contact conditions between rolling elements and raceways in SRBs display non-linear stiffness behaviours, the system being modelled in this case reacts only through bedplate forces and not coupled moments and forces (where non-linear stiffness properties would determine the load 'share' between force and moment reaction contributions). As such, the overall reaction force of the bearing housing required to balance the total system remains the same regardless of internal interactions. Non-linear contact behaviour is certainly important when one is seeking to resolve distributed loads internally, but, in the current study it is the overall reaction forces which are of interest. Internal load distributions will be considered as part of the next stages of future work which will increase model complexity to that level.

Thank you for noticing we have not stated whether or not bearing clearance has been taken into account. In this instance we have assumed that there is no bearing clearance since this parameter is known to drive the internal load distribution, rather than overall reaction force. This point will be added to the updated manuscript.

We also agree that our description of how the mesh was obtained can be much improved. A convergence study was in fact carried out to determine the mesh density and a description of this will be included in the updated FE model description.

Review comment:

Also in the case of the tapered roller bearing, it is not apparent whether the contacts

Printer-friendly version

Discussion paper

between the raceway surfaces and rolling elements were taken into account in the FE model. It seems as if the bearing was modelled as a piece of solid material. If this would be the case, it would have to be questioned to what extent the translational and torsional stiffness of the main bearing can be represented by the FE model. It is also indicated that the preload of the taper roller bearing is taken into account. The author should indicate how exactly the preload is considered.

The analytical model is enhanced by an torsional stiffnesses of the tapered roller bearing. These stiffnesses are set constant and with that a linear stiffness behavior is indicated. In the case of roller bearings a non-linear stiffness behavior can be assumed (hertzian contact, clearance). The author should evaluate which error must be accepted for this simplification.

Response:

Both of these comments tie into the opening of this response and the main goals of this study. You are correct that the load shared between force and moment reactions within the TRB will be determined by the stiffness behaviour (as was touched on above) in the bearing, however, TRB are known to have only weak non-linear behaviour (with a deflection exponent value of 1.1) and TRBs, along with CRBs, are often approximated as linear in their load response. This type of bearing can therefore be approximated to behave like linear steel sections in the FE model and then, since it is the type of load reaction (forces and moments) rather than any one specific design, we have approximated this with a piece of solid material. This is in-line with the stated goal of the paper outlined in the first part of this response (and to be added very clearly into the revised manuscript) to explore how well analytical models might recreate the loads experienced by a support which reacts both forces and moments. This discussion of the modelling assumptions employed, and their viability should have been included in the original manuscript and so we are very grateful you have brought this oversight to our attention. To be clear, we are not proposing that the FE models we employ here should be used to represent real world TRBs, we are developing a methodology from which someone can use an accurate FE representation of their TRB bearing to develop fast and representative analytical models suitable for use in large numbers of load analysis cases, development of digital twin models across a large turbine fleet or similar applications where computationally expensive FE analysis is not viable. The results of this work demonstrate that, up to the level of models employed here, this can be done for both SRB and TRB reaction behaviour types. With respect to the added torsional springs being linear, under small deformations (such as those present in bearings) a torsional spring is equivalent to a pair of parallel linear springs and hence the fact that TRB contact behaviour is only very weakly non-linear indicates that a linear torsional spring is a reasonable approximation. This point will be revisited in future work where internal forces and deformations are considered as modelling complexity is increased. We will also ensure that the above points are clear in the updated manuscript.

As we are interested in the overall forces and moments, the bearing preload effectively gives further justification for assuming the bearing and housing are a solid piece of material (no clearance) – we'll make this point clearer in the updated manuscript.

Review comment:

The author should also add the assignment of stiffnesses K and KR in the figures

Response:

K1, K2 and KR will be added to the figures and the values given in the figure description.

Review comment:

In general the results are well presented

The literature does not show the state of the art concerning modelling main bearings of wind turbines. Especially the modelling techniques used for FEM calculation should be updated.

Response:

We also agree that more literature pertaining to the modelling of wind turbine main bearings would strengthen this piece of work and this will be included in the updated manuscript. This will include ref [2-7] among others.

References

[1] Wang, S., Nejad, A. R., Bachynski, E. E., and Moan, T.: Effects of bedplate flexibility on drivetrain dynamics: Case study of a 10MW spar 95 type floating wind turbine, Renewable Energy, 161, 808–824, https://doi.org/10.1016/j.renene.2020.07.148, https://linkinghub.elsevier. com/retrieve/pii/S0960148120312246, 2020a.

[2] Bosmans, J., Blockmans, B., Croes, J., Vermaut, M., and Desmet, W.: 1D-3D Nesting: Embedding reduced order flexible multibody models in system-level wind turbine drivetrain models, in: Conference for Wind Power Drives, 2019.

[3] Cardaun, M., Roscher, B., Schelenz, R., and Jacobs, G.: Analysis of Wind-Turbine Main Bearing Loads Due to Constant Yaw Misalignments 80 over a 20 Years Timespan, https://doi.org/10.3390/en12091768, www.mdpi.com/journal/energies, 2019.

[4] Gaertner, E., Rinker, J., Sethuraman, L., Zahle, F., Anderson, B., Barter, G. E., Abbas, N. J., Meng, F., Bortolotti, P., Skrzypinski, W., Scott, G. N., Feil, R., Bredmose, H., Dykes, K., Shields, M., Allen, C., and Viselli, A.: IEA Wind TCP Task 37: Definition of the IEA 15- Megawatt Offshore Reference Wind Turbine, Tech. rep., https://doi.org/10.2172/1603478, www.nrel.gov/publications.https://www.osti.gov/biblio/1603478

[5] Kock, S., Jacobs, G., and Bosse, D.: Determination of Wind Turbine Main Bearing Load Distribution, in: Journal of Physics: Conference Series, vol. 1222, https://doi.org/10.1088/1742-6596/1222/1/012030, 2019.

[6] Wang, S., Nejad, A. R., and Moan, T.: On design, modelling, and analysis of a 10-MW medium-speed drivetrain for offshore wind turbines, Wind Energy, 23, 1099–1117, https://doi.org/10.1002/we.2476, https://onlinelibrary.wiley.com/doi/abs/10.1002/we.2476, 2020b. [7] Torsvik, J., Nejad, A. R., and Pedersen, E.: Main bearings in large offshore wind turbines: Development trends, design and analysis requirements, in: Journal of Physics: Conference Series, vol. 1037, p. 42020, https://doi.org/10.1088/1742-6596/1037/4/042020, 2018.

Interactive comment on Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2020-58, 2020.