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Gearbox loads caused by double contact simulated with HAWC2

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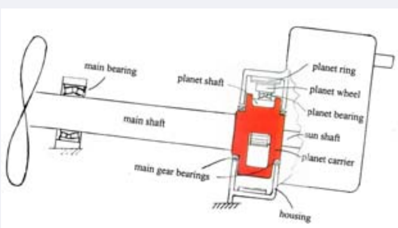
Abstract

The aim of the work is to investigate if a special event named "double contact" or "tooth wedging" between individual gear wheels inside a gearbox can cause high internal transient loads and lead to gearbox failure. The investigation is made by interfacing a non-linear simulation model of the dynamic behaviour of a gearbox to the aeroelastic code HAWC2. The response of the coupled simulation models are then analyzed in order to see if and under which circumstances the double contact event occurs and which loads are achieved inside the gearbox, caused by the radial force reactions.

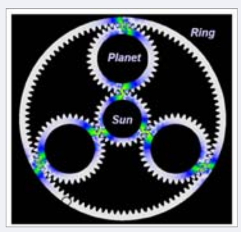
The gearbox concept analyzed also works as the second main shaft bearing. Hereby all force reactions from the rotor as well as the gravity and inertial loads from the gear box itself will be transferred through the main bearings between carrier and housing down to the gearbox suspension normally consisting of two rubber bushing arrangements. A special and important feature of the planetary gear is the floating sun-wheel suspension which ideally ensures an excellent load distribution between the three planets. The theory of this paper is that the load transfer through the main bearings can cause a double contact situation inside the planetary stage if an unfortunate ratio between bearing clearance and tooth clearance occurs. This condition destroys the load sharing between the planetary wheels and creates large bearing forces in the drive direction due to radial forces.

Model

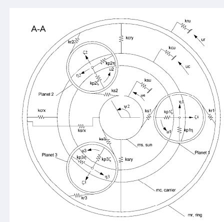
A 2D gearbox model containing the translational and rotational modes of a planetary gear stage has been developed. Bearing springs are assumed linear whereas the tooth forces are non-linear taking only pressure. In order to enable a double contact situation also tooth springs on the backside are included. The gearbox model has been connected to a full aeroelastic model of a wind turbine so the coupling is fully integrated.



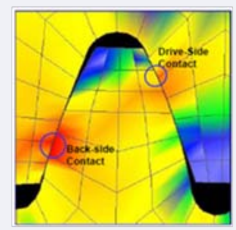
A traditional layout of the drive train is modeled where the gearbox also acts as the second main bearing. The rotor loads, weight and inertial forces of the gearbox are carried by the planet carrier.



Load pattern during normal operation when loading is as expected with pressure on one tooth side only



2-dimensional model of planetary gear stage with lumped springs represen-ting tooth and bearing stiffness.

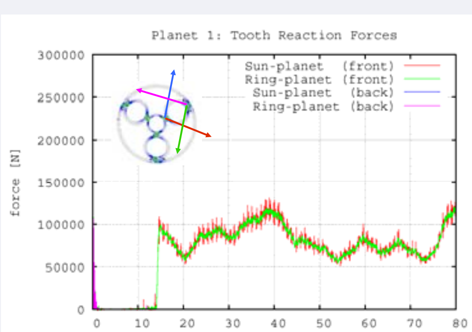


In case of large bearing clearance a double contact can occur, where the tooth backside is also in contact.

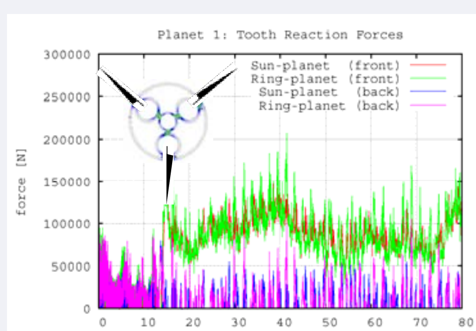
In case of a double contact the sun can be "caught" by two planets causing an uneven load distribution.

Results

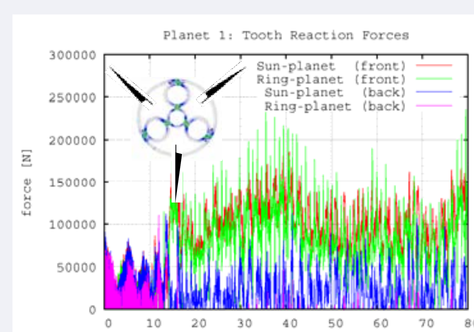
The three plots below all show results from an aeroelastic simulation with the same input parameters, i.e. same turbine model (600kW stall regulated), same wind (10m/s) and same turbulence time series. Only the gearbox models differ. The four graphs in each plot show the gear tooth reaction forces on planet wheel #1 between *sun/planet* and *ring/planet* on the *front* side and *back* side of the tooth, respectively.



Normal operation case without double contact. The variation in loading is caused by turbulent wind speed variation. Tooth force directions are illustrated with arrows.



Large carrier bearing clearance is applied which causes double contact. Loads are increased significantly. The rotor is "mounted" so that the three planets are aligned with a blade.



Same gearbox as the one to the left, but the "mounting" of the gearbox relative to the blades is rotated 60deg. This results in an even larger load increase.

Conclusions

High clearance in the planet carrier bearings in combination with low tooth clearance (backlash) increases the risk of double contact. If this occurs, the internal forces on teeth and planetary bearings are significantly increased due to an uneven load sharing between the planets. In this condition the radial forces transferred between the planetary wheels and the ring are approximately added directly to the planet bearing forces in the driving direction and not as a square root sum, as one might expect. The additional planet bearing loads originating from the rotor bending moments are dependent upon how the three planets in the gearbox are positioned relative to the three blades with a maximum depending upon turbine characteristics. This might contribute to the explanation of gearbox failures seen in the past and explain the variability in failures of apparently identical turbines as the mounting azimuth position is random.

References

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2. Guo Y., Parker R. G., Dynamic modeling and analysis of a spur gear planetary gear involving tooth wedging and bearing clearance nonlinearity, European Journal of Mechanics A/Solids (2010), doi: 10.1016/j.euromechsol.2010.05.001