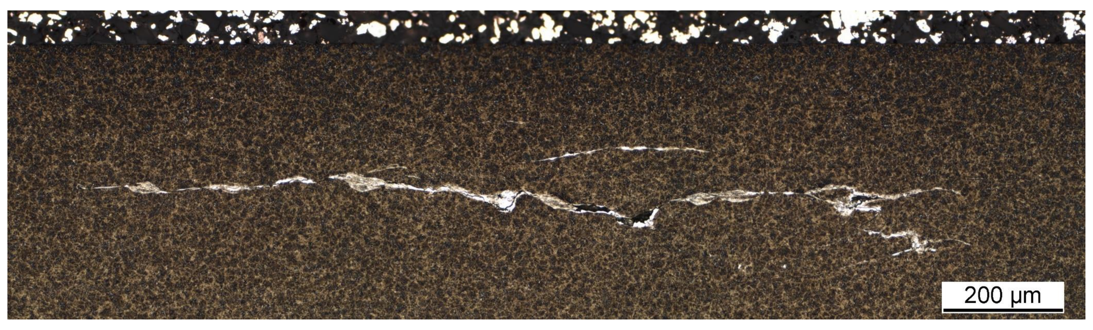
Multiscale analysis of **W**hite **E**tching **C**racks (WEC)

Bearing analysis: From tribological contact to full-scale wind turbine nacelle

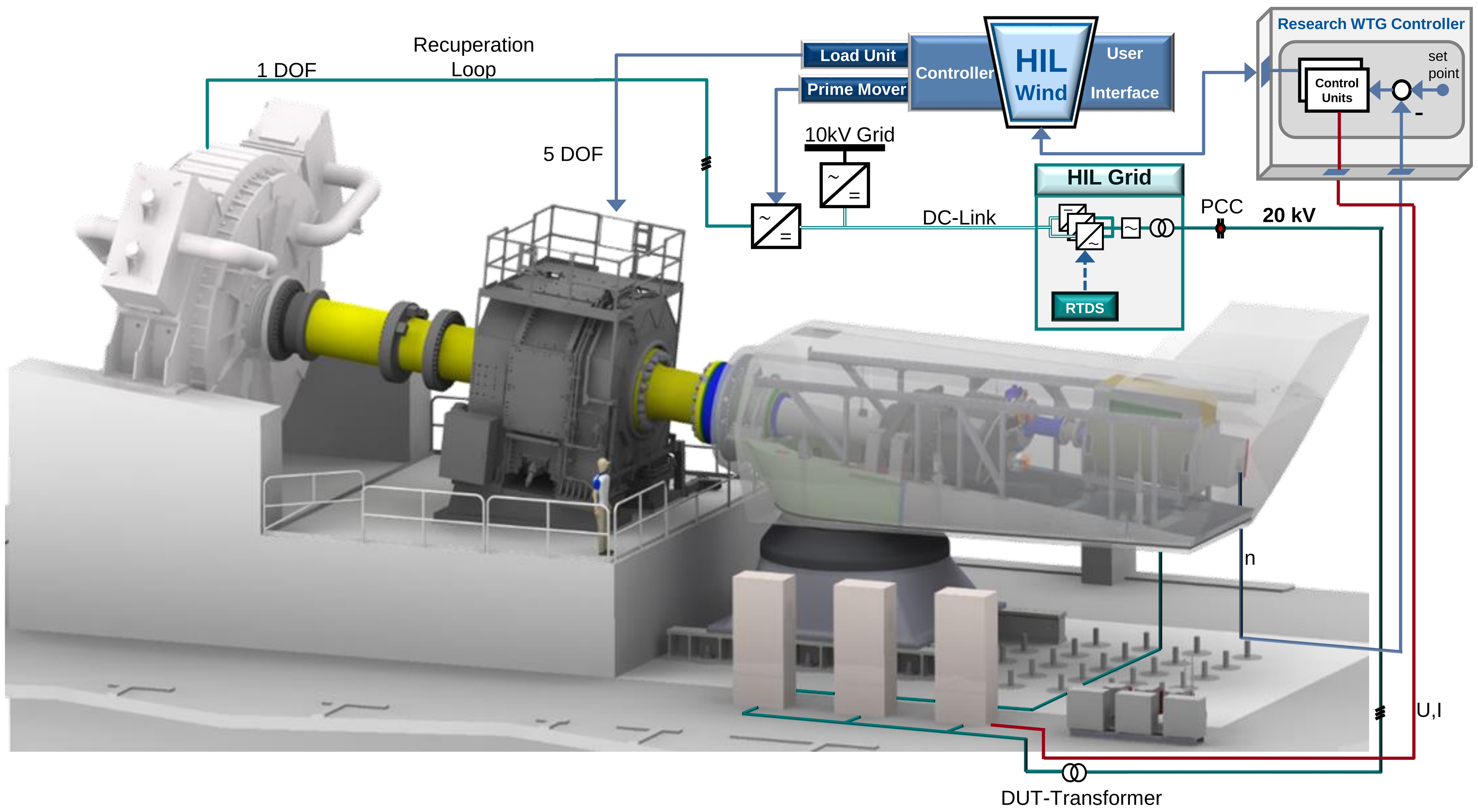
Abstract

Nowadays, the so-called White Etching Cracks (WEC) are a common cause for premature rolling bearing failures in wind turbine gearboxes, significantly increasing the maintenance costs. These undirected, three-dimensional cracks are usually flanked by regions of altered microstructure and ultimately lead to a cracking or spalling of the raceway.

Ongoing research on both component and tribological contact levels has led to several WEC-critical test conditions that may be linked to operating conditions encountered during field operation. Therefore, it is planned for 2017 to investigate White Etching Crack (WEC) phaenomena on nacelle system level within main gearbox tests. Future research aims for an insight into critical operating stages that could lead to a bearing failure.



Axial cross-section showing branched crack networks and white etching features (Nital 3 %)



Multi-physical HIL integration of a full nacelle

Objectives

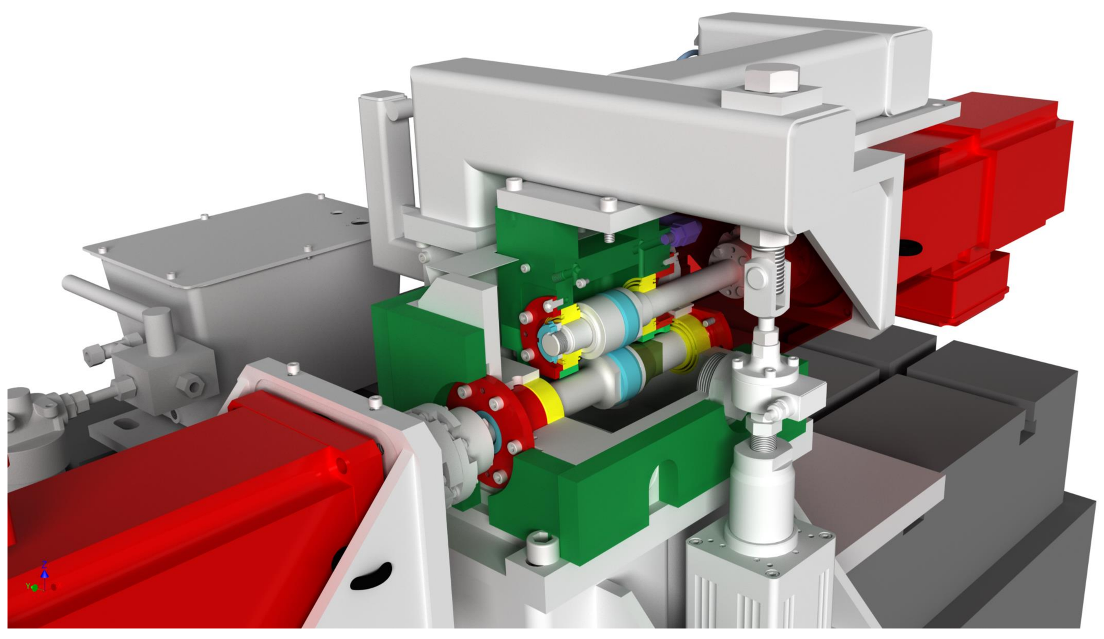
- Identification of WEC-drivers
- Determination of threshold values for WEC-drivers and their combination
- Correlation of critical conditions in tribological contact and component test level with in-field conditions
- Improvement of existing and future designs
- Improvement of operating strategy

Approach

- Investigation of individual parameters on tribological contact level
- Transfer of critical conditions to component level
- Analysis of the tribological and component load conditions during critical operating stages on nacelle system level

Tribological contact level

Over the last years component level test rigs had been used to investigate WEC through the use of complete bearings. The influence of individual contact parameters can, however, only be studied on tribological contact level test rigs. Through experiments on a two-disc test rig, it was determined that both Slide-Roll-Ratio and the lubrication condition have an influence on the WEC formation.



Two-disc test rig

Besides the influence of mechanical parameters a four-disc test rig is used in order to evaluate the tendency towards WEC through the application of electrical and chemical additional loads.

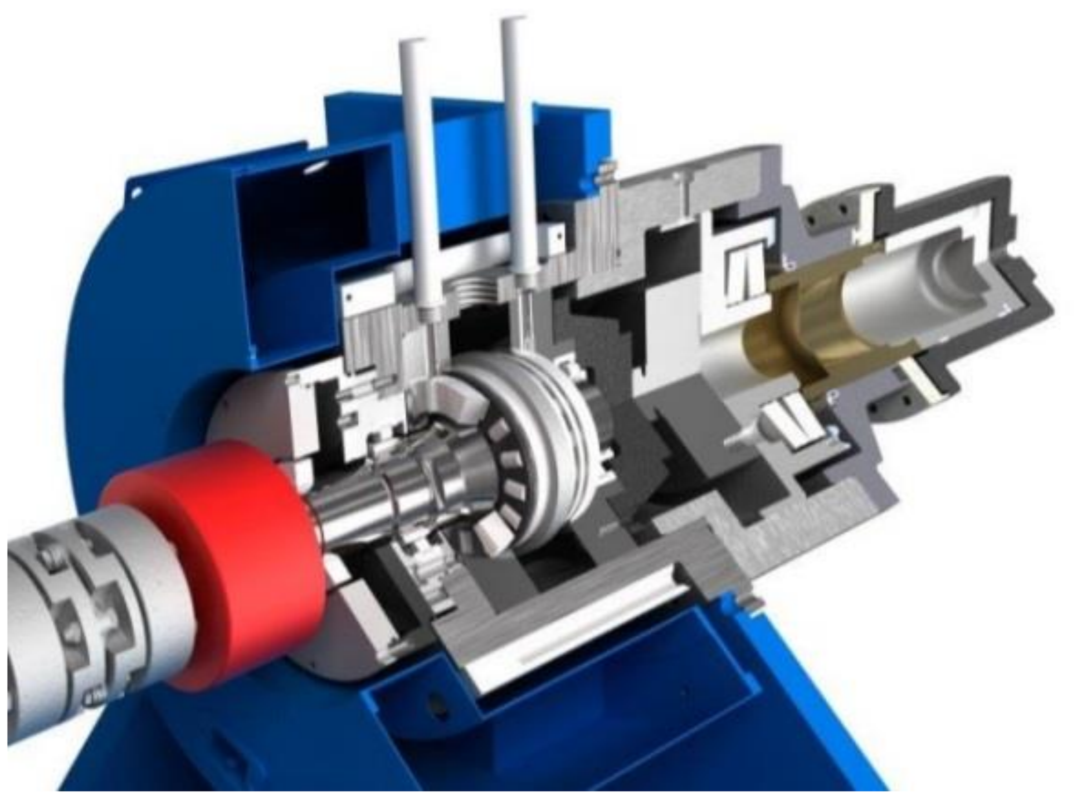
Initially, the RCF test rollers were loaded with hydrogen by immersion in aqueous solution of sulphuric acid with CH_4N_2S. Liquid nitrogen is used to prevent hydrogen diffusion during sample transport and mounting. The main goal of the tests was to study the influence of the concentration of diffusible hydrogen on the WEC formation.

A further test series investigated the influence of electrical current on WEC formation during rolling contact fatigue. For this purpose, a defined contact current was applied between the RCF test rollers and the loading rollers. Testing determined the influence of the current strength and the polarity on the roller lifetime.

Both tests results, using hydrogen pre-loaded specimens and under electrical load confirmed that these factors can be seen as critical WEC-drivers.

Component test level

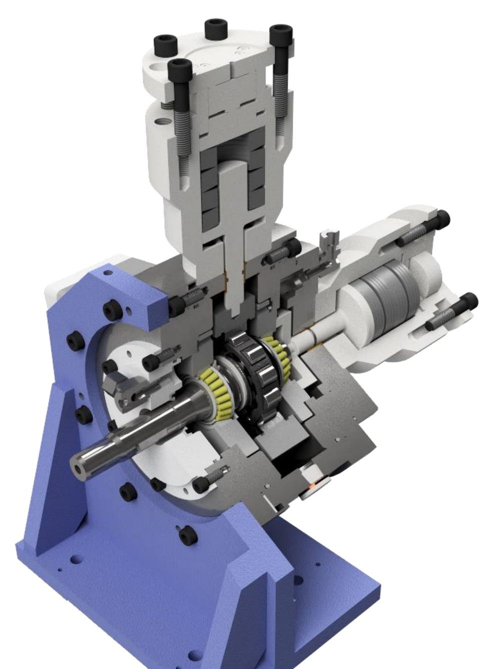
Stationary operating points were examined with respect to WEC formation on a rolling bearing test rig, using cylindrical roller thrust bearings (81212). WEC have been reproduced repeatedly under different conditions, both on washers and rollers. Within the framework of this test series, WEC-induced failure appears under constant contact conditions in mixed friction regime ($\lambda < 1$). Furthermore, the results suggest that the present high level of kinematic slip together with the high frequency of over-rolling under load, leads to critical operation conditions.The WEC were not observed to be connected to the surface and WEA were only found in combination with cracks.



Thrust bearing test rig

On the basis of the results from the four-disc machine and other studies, a defined contact direct current was imposed on cylindrical rolling bearings (NU206) under static radial load. The run time until WEC-failure was dependent of the current density *J* in the Hertzian contact area. These results indicate that for the adjusted parameters and pre-defined run time, the exceeding of a limit value of the current density *J* leads to WEC formation.

Moreover, only the rolling elements and inner rings, which were connected to the plus pole (anode) of the current source, formed WEC. Evidently, electrical current is not self-sufficient to explain WEC formation, as WEC failure in the FE8 testing are most likely not electric related. Nevertheless, the results clearly demonstrate that the current density can be a critical driver for WEC reproduction on radial roller bearings.



Radial rolling bearing test rig

Nacelle Testing

Due to the neglection of the interactions and interface between the individual components and subsystems the test configurations on a test rig are merely simplifications of the real system. For a realistic approach of WTG nacelles, subsystem or component tests on test rigs, load cases must be applied comparable to in-field conditions. To accomplish these realistic load cases, emulated wind and grid conditions are necessary.

Therefore, future research regarding the White Etching Crack (WEC) phaenomena will be conducted on nacelle system level within main gearbox tests on a 4 MW WTG test bench .

The test bench is equipped with a 6 DOF wind load application system. The prime mover consists of a PM direct drive with a power of 4 MW. The non-torque loads (thrust, tilt & yaw Bending, etc.) are applied by a load application system (LAS). The LAS operates with 12 pairwise pre-loaded hydraulic actuators and is used to emulate the turbines rotor system with a Hardware in the Lood (HIL) approach.

The nacelle is connected to a 22 MVA grid emulation system, which provides full Fault Ride Through (FRT) capabilities.

Device under test on the 4MW WTG system test bench

Conclusion

Experimental and analytical investigations on tribological contact and component level suggest that influencing and maybe necessary drivers can vary from one application to another and the practical relevance of model-test rigs remains limited. Furthermore, preliminary findings suggest relationships between microstructural features of WEC and operation conditions, notably with the hydrogen pre-loading.

However, size does matter: While several influences are unaffected by the size, many of the relevant effects like global deformation on local contacts or slipping have to be analyzed within full size tests.

The lack of knowledge about the overall system behaviour and the complex interaction of the drivetrain requires particular realistic ground tests of nacelles to solve reliability issues. While field testing of prototypes is too expensive and single component testing not sufficient, full size ground testing remains the only suitable way to increase and improve the development of future wind turbines.

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