Hydraulic Yaw System

Stubkier, Søren; Pedersen, Henrik C.; Mørkholt, M.

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Hydraulic soft yaw system for load reduction

1. Introduction
As wind turbine increase in size, combined with increased lifetime demands, new methods for load reduction need to be examined. One method is to make the yaw system of the turbine soft flexible and thereby dampen the loads to the system, which is the focus of the current paper.

2. Advantages of hydraulic yaw systems
The hydraulic yaw system will operate as a shock absorber system on a car, hence leading the loads away from the wind turbine structure and into the hydraulic system where it can be dissipated instead.

3. Wind turbine model
The model parameters are based on the data of the NREL 5MW turbine. Most of it (17) is taken from the HAWC2 code, which includes the constraints, mass moment of inertia, damping and spring stiffness of the soft yaw system.

4. Optimization of Stiffness and Damping
As described the objective of the soft yaw system is to lower the ultimate and fatigue loads on the turbine by limiting the system in a controlled manner. The movement is controlled by the stiffness, K, and damping, B, of the system. To find the optimal solution for this, a graphical solution method is chosen. It is desired to minimize both extreme loads and fatigue loads, why the objective is to minimize

\[ f(K,B) = M_{ext} + M_{at} \]

where \( M_{ext} \) is the extreme load on the yaw system and \( M_{at} \) is the equivalent fatigue load on the yaw system. What is based on nonlinear counting and Pohlgren's partial damage hypothesis.

To find an optimal value of both K and B HAWC2 is utilized. All 24k simulations with different variations of K and B are performed. The values of K and B are selected to fit a damping ratio \( \zeta \) of 0.5 of a simplified linear model, see Stubkier and Pedersen (1) for a more profound analysis.

The results from HAWC2 are shown in figures 2 and 3. The simulation K is the one with the lowest stiffness.

5. Results I
Figure 2 clearly shows how the cost increases with smaller angular movements for simulations at 24 [m/s]. Figure 3 shows the maximum load on the system compared with the maximum angular movement. Notice how the loads decrease when angular movements are below 20 degrees and rises again when the loads angular movements are below 5 degrees. This indicates an optimal solution range.

6. Results II
Figure 4 shows that the loads decrease significantly up to 37 degrees, but then increase again with larger angular movements. Figure 5 shows that the loads from the soft yaw systems are significantly lower than the loads from the hard yaw systems. The results are outlined in table 2.

7. Load reduction
Figure 4 and 5 shows the result from simulations of the wind turbine with the soft yaw system compared to the soft yaw concept with the parameters of K and B corresponding to the optimal values of figure 3. As shown in the figures, huge reductions in fatigue and ultimate loads are found for the yaw system and rotor shaft. There is a small increase in the blade fatigue bending torque and the lifting torque of the tower. The results are outlined in table 2.

Although difficult to quantify, the improvements achieved are significant. Either by increasing the life time of the turbines or by moving the loads into a more manageable area of the turbine. The results are outlined in table 2.

8. Test rig
The test rig consists of 8 hydraulic internal gear motors, which represent the hydraulic soft yaw system in combination with hydraulic accumulators.

9. Results III
To obtain the 20 year duty cycle data in the form of speed and load of the hydraulic motors and the different DLCs, ranging from 1...25 [m/s] are combined by extrapolating the data for the 20 year period.

The load spectrum and amplitude is taken from the HAWC2 DLC's simulations in order to investigate the behavior of the hydraulic system.

The poster presented the advantages, turbine mounting, optimization and results of the soft hydraulic concept. Further a full scale test rig is presented for further testing. It is concluded that the results from the loads extrapolated over 25 years shows huge reductions in fatigue and ultimate loads on the wind turbine. Especially the fatigue loads on the yaw system are reduced significantly.

On the hardware side duty cycles for a hydraulic yaw system consisting of eight motor/gear units is presented. This is done for a simple model including friction. Finding the right hardware, which can handle 20 years of operation with the presented duty cycles will lead to significant load reductions on the wind turbine structure.

This might increase the cost of the yaw system compared to an original stiff system, but the total cost of ownership for the wind turbine is expected to be reduced significantly.