Session topic: Turbine technology
Sub-topic: Drive trains and generators

Abstract

Structural Optimization of an Innovative 10 MW Wind Turbine Nacelle

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Introduction

For large wind turbine configurations of 10 MW and larger capacities, direct drives present a more compact solution over geared solutions. Further, if the generator is placed in front of the wind turbine hub, a compact “king-pin” drive solution is designed [1, 2], which allows the generator to be directly coupled to the hub. In the present study, the detailed structural design of the 10 MW king-pin drive and nacelle is made using extreme loads obtained from the 10 MW reference wind turbine. The ultimate design stresses of critical components are determined, and based on which, the tower top mass is minimized.

Approach

The design concept of 10 MW wind turbine with a 178 m rotor diameter is presented hereunder. Key features of presented turbine are generator mounted in front of the rotor blades and king-pin nacelle layout. In figure 1, a detailed view of the turbine nacelle is presented.

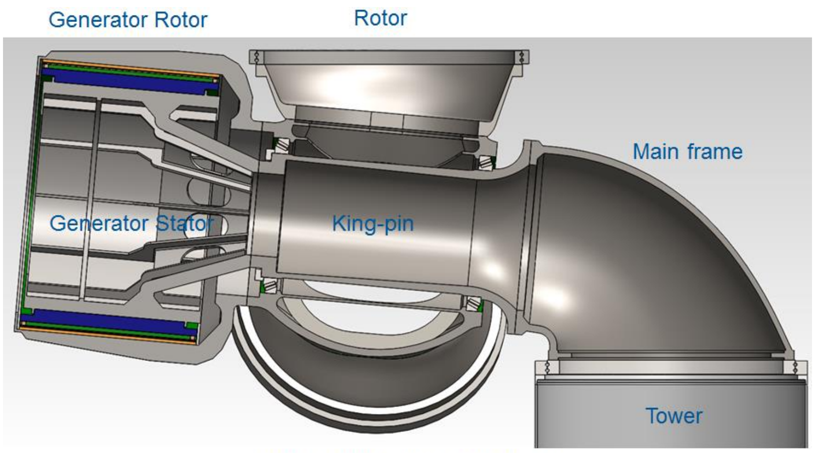

Figure 1 King-pin nacelle layout

In presented design, the drivetrain is supported by two bearings, upwind and downwind, on the king-pin. The king-pin is fixed to the mainframe, which is connected by the yaw bearing with the

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tower. On the upwind side of the king-pin is connected the generator stator. The rotor with generator rotor rotates relative to the generator stator, which is fixed to the king-pin.

The design in figure 1 is conceptual and further refinements are required in terms of 1) jointed connections between the mainframe and the king-pin, 2) generator and king-pin and 3) avoidance of stress concentration regions; the details of which are presented herein. In the study, stress analysis by application of finite element method is done to ensure the structural integrity. Analysis of stress distribution on the drive train components allows to verify safety of the design and to determine areas that can be modified to reduce structural mass of the nacelle.

Main body of abstract

The load carrying sections from the rotor of the generator to the king-pin are analyzed to determine regions of stress concentration. The high stress concentration areas are caused mostly by sharp edges. In presented design few sharp edges on profile were found and modified by adding fillets or increasing existing fillets radius. In figure 2a, geometry of the mainframe and king-pin after modifications is presented.

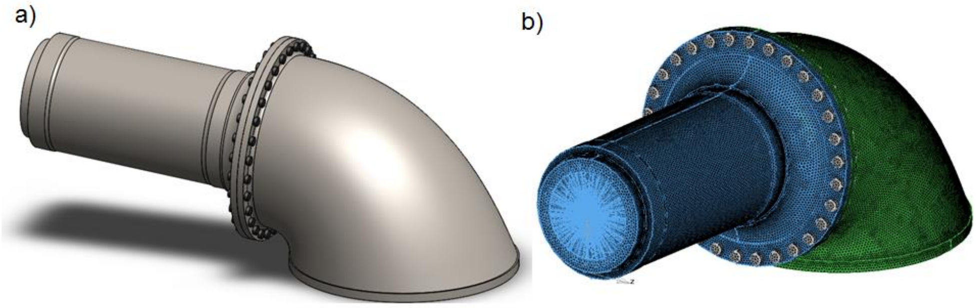

Figure 2 Mainframe and king-pin connected by bolted flange, a) geometry, b) FE model

After these modifications, the bolted flange connection was designed to connect the king-pin with mainframe. This connection is crucial because all loads derived from the rotor and generator are transferred by the king-pin and mainframe to the tower. The king-pin is twisted by a torsional moment from generator as well as bent by a moment derived from the rotor. The bending moment is the result of rotor interactions on the upwind and downwind bearings during wind turbine operations, and it acts in the horizontal axis that is normal to the rotor rotations. Additionally, on the main bearings is acting thrust force that is derived from the blades. In the bolted connection 30 bolts with diameter 100 mm and class 10.9 were assumed [3]. For chosen bolts class the design shear strength for one bolt is about 487 MPa, including safety factor of 1.2. The parameters of bolted connection are preliminary and they will be verified on the basis of finite element simulations to provide safety of the design and minimum mass of the nacelle components.

To obtain stress distribution on the drive train components a three-dimensional finite element model in HyperWorks software was built, as shown in figure 2b. In structural components with bolts the main stress concentration areas are due to Hertzian stress in contacts between bolts and components. To properly determine stresses in joined flange connection, a detailed three-dimensional bolted connection including bolts geometry and contact areas was modeled [3, 4]. The geometry and model of the bolted connection are presented in figure 3.

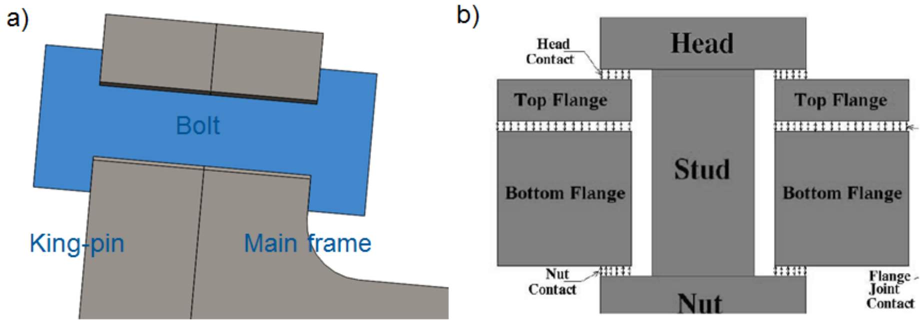

Figure 3 Bolted connection, a) geometry of connection, b) model of bolted connection

In the finite element model contact surfaces including friction were modeled between the bolt heads and top flange and the bolt nuts and bottom flange as well as contacts were assumed between two flanges.

To calculate stress distribution on the wind turbine parts following loads including safety factors were applied: bending moment from rotor 18300 kNm, thrust force 4600 kN and torsional moment from generator with value of 16500 kNm. The torsional moment from generator was applied on the king-pin in connection area with generator stator. Applied forces were estimated on the basis of ultimate loads obtained from HAWC2 simulations for 10 MW DTU reference wind turbine [5]. The simulations were conducted for DLC 1.3 from IEC 61400-1, which was the critical case for extremes. In a bolted connection crucial is the pretension force, which determines how rigidly the two parts are connected and the level of stresses in contact areas. In the study, the pretension force of 400 kN was applied on each bolt in the flange connection. It was investigated on the basis of series of simulations, in such way to not exceed allowable stress limit on the structural components and to provide proper stiffness of connection. The model was constrained on the bottom part of the mainframe. Stress simulation results are presented in figure 4.

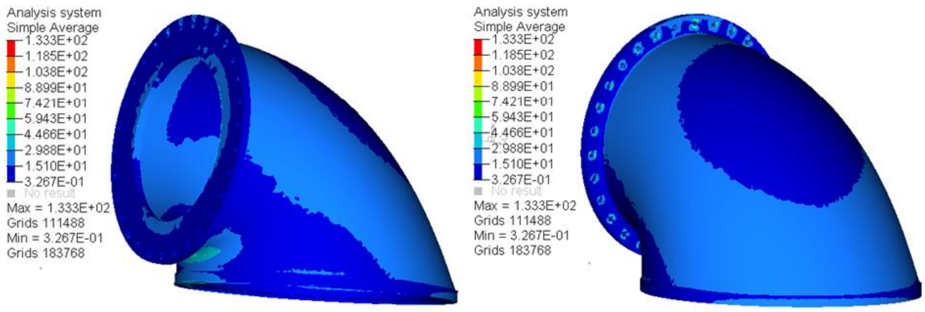

Figure 4 Von Mises stress distribution on mainframe

Concentration of von Mises stress on the mainframe is observable in the bottom part as well as in place of contacts between bolts and flange. Analyzing stresses on the king-pin component presented in figure 5, it is visible that they are concentrated in upper part of the flange and in the sharp edges for bolts holes.

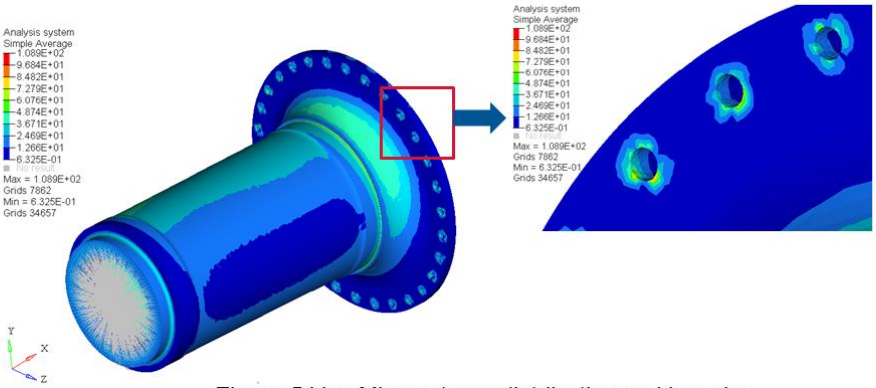

Figure 5 Von Mises stress distribution on king-pin

The two parts, king-pin and mainframe are connected by bolts on which pretension force was applied before. The maximum stress in bolts occurs in the stud, and it is about 66 MPa, what is presented in figure 6.

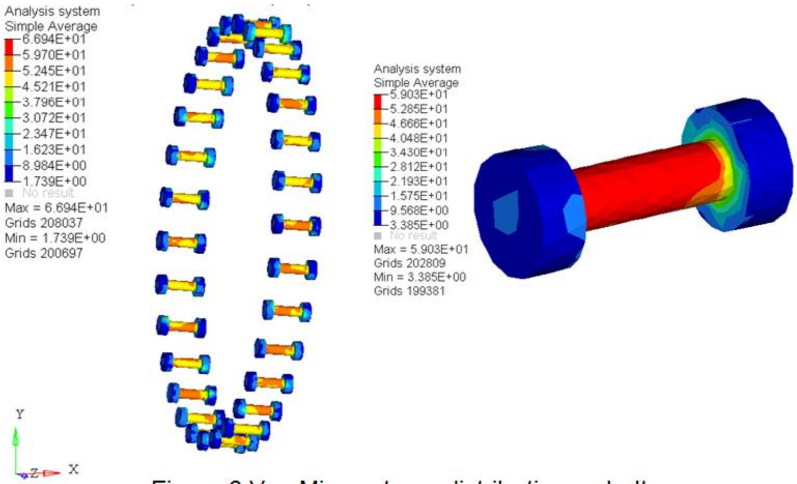

Figure 6 Von Mises stress distribution on bolts

In presented model maximum von Mises stress were recorded on the mainframe component in the contact surface between bolts head and flange, and it has the value 133 MPa. In the study, it was assumed that the mainframe and king-pin are made from the structural steel with yield strength 250 MPa. The safety of the design can be verified on the basis of following equation

$$\sigma_v \leq \frac{1}{\gamma_m}\sigma_y \tag{1}$$

Where σ_v is the von Mises stress, σ_y is the material yielding strength and $\gamma_m = 1.2$ is the safety factor for material strength. The design value of yielding strength for material strength is 208 MPa, and it is higher than the maximum value of stress on the structure simulated by FE model that is 133 MPa.

Conclusion

In the abstract, innovative nacelle design of 10 MW offshore wind turbine was presented. The total nacelle mass of presented turbine excluding generator is 166 tones. Main contribution to this value has the king-pin and mainframe. It is proposed to reduce this mass by application of structural optimization methods on chosen areas of the components. In this study it was shown that ultimate stresses on the drive train components do not exceed the design limit and that several areas on the components have low stress concentration, providing the means for mass reduction. Presented analysis shows that structural mass of the nacelle components can be reduced without negative influence on the mechanical properties of the structure, e.g. for the mainframe the mass can be reduced from upper and side parts.

In the future, topology optimization methods will be used to propose new design of the drive train components and nacelle configuration that provides minimum cost for large capacity offshore wind turbines. Additionally, proposed preliminary bolted connection will be redesigned due to cost of the bolts and limitations which appear for structural material in the flanges and tooling.

Learning objectives

- Design of an innovative 10 MW wind turbine drive train and nacelle
- Ultimate stress analysis of the main parts of the nacelle
- Structural optimization of drive train components

Acknowledgments

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