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MODELLING OF THE VARIABLE LOADS OF THE WORK OF THE CLASS WIND TURBINES

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Abstract

This paper investigates some possibilities for suitable modeling of variable external loads in a regime of exploitation of a kind of wind turbines. On the base of the developed original model of wind turbines it is possible to study dynamical processes in different specific work regimes of this kind of wind turbines. This model allows to examine the behavior of the system in extraordinary situations and different work regimes and to define some recommendations for more effective work of that kind of wind turbines.

Key words: effectiveness, multibody dynamics, wind turbines.

Introduction

One of the important problems in development of wind turbines is provision of high effectiveness in different work regimes. The necessary safety and ecology in work must be provided. The analysis of modern technical decisions concerning these problems points the main tendencies in development of these machines. Higher towers which provide the necessary height of the rotor for better speed of the wind are used in current constructions. It is necessary to use rotors with blades that have bigger dimensions. Except these advantages, the wind turbines have also some disadvantages. For example, there are problems with appearance of extra loads in the construction. These loads require extra limits in their designing, manufacturing, installation and exploitation. To satisfy the requirements, modern options for modeling of dynamic processes in the machines.

The increase in the rotor size and hence the turbine size leads to a complicated design of a drive train in the wind turbine besides higher requirements of turbine reliability. Design calculations for wind turbine base on simulation of mechanical loads on the turbine components caused by external forces. The external forces are the wind, the electricity grid and sea waves for offshore applications (Hansen 2001). The various simulation techniques are used to analyze the loads on internal components of drive trains. The first approach is the multibody system formulation and it is typically used for the simulation of wind turbine dy-

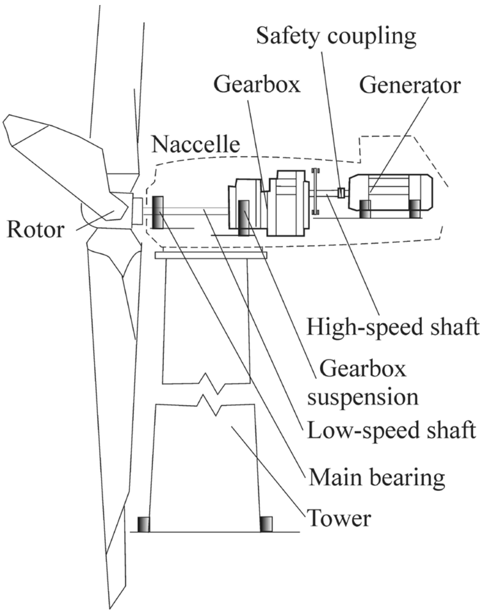

Fig. 1. Schematic sketch of wind turbine.

namics. All drive train components are treated as rigid bodies with maximally 6 DOF's corresponding to 3 translational and 3 rotational motions. Each body has mass and inertia properties, but cannot deform. The joints between the bodies represent the flexibility in the system. This approach yields a set of ordinary differential equations. The second approach is the finite element modeling techniques. Finite element models are used for internal analysis of the individual components. These models add a possibility of calculating stress and deformation in the drive train components continuously during the time. This approach yields a set of partial differential equations. Each addition to the model leads to additional information about dynamics of the drive train but makes the modeling and the simulation more complicated.

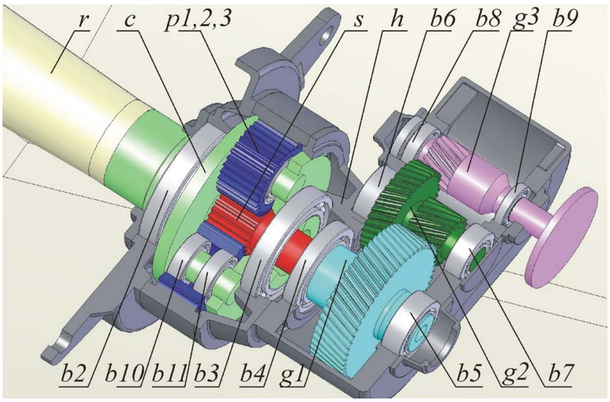

Fig. 2. Sketch of gearbox.

r – rotor, *c* – carrier, *p1÷3* – planets, *s* – sun, *g1÷3* – gears, *b2÷11* – bearings, *h* – hull

Dynamical Model

An original dynamical model of a wind turbine drive train is developed (Vukov 2009, Todorov and Vukov 2007, 2009a). It includes all parameters of a wind turbine drive train – the designer's, the inertia's, the mass`s. It includes also the contact forces between gear pairs, bearing and shaft stiffness, gearbox suspension flexibility and flexibility of safety coupling between the gearbox and the generator. The most wind turbine components are considered with 6 degrees of freedom.

The schematic sketch of a wind turbine is shown in Fig. 1. The wind turbine consists of

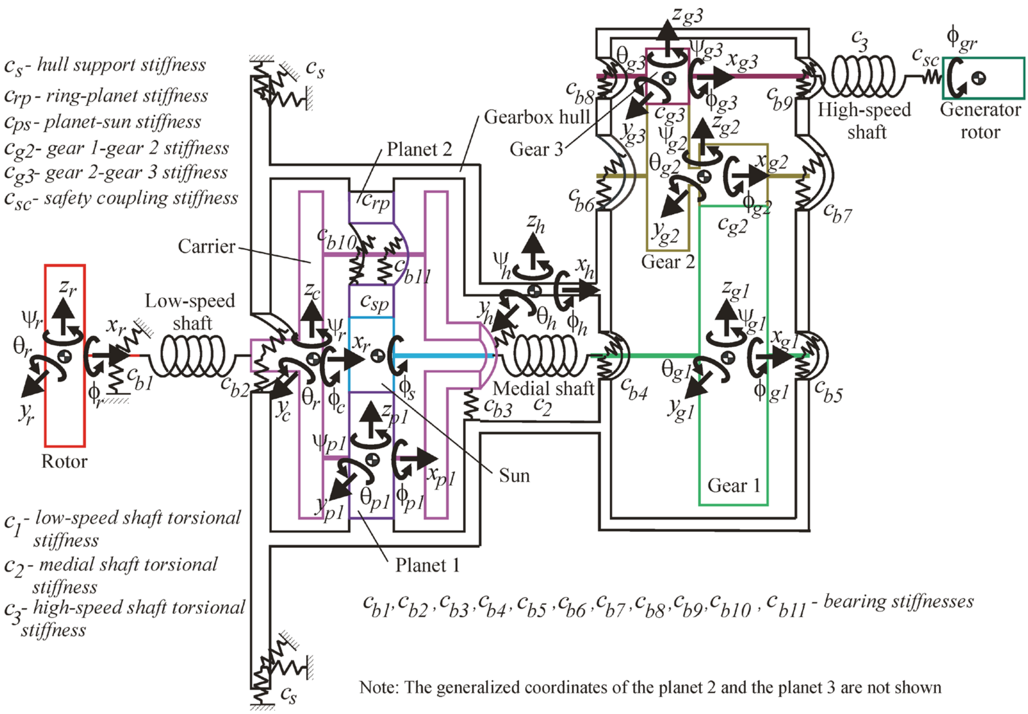

Fig. 3. Wind turbine dynamic model.

a rotor with three blades, a low-speed shaft, a gearbox, a high-speed shaft, a safety coupling and a generator.

The gearbox`s sketch is shown in Fig. 2. The gearbox has three stages. It consists of a low-speed planetary gear stage (three identical planets with spur teeth, a sun and a fixed ring wheel) and two high-speed stages (helical gear pairs).

The dynamical model of the wind turbine is shown in Fig. 3. The model has 11 bodies and 53 DOF's.

The gear contact forces between wheels are modeled by linear spring acting in the plane of action along the contact line (normal to the tooth surface) (Brandlein 1999, Shabana 2005). The stiffness gear is defined as the normal distributed tooth force in the normal plane causing the deformation of one or more engaging tooth pairs, over a distance of 1 μm, normal to the envolvent profile in the normal plane. This deformation results from the bending of the teeth in contact between the two gear wheels, of which one is fixed and the other is loaded. Damping and friction forces are not included. These assumptions are valid for heavily to moderately loaded gears (Thomsen et al. 2003).

The bearings are modeled as springs. The bearing stiffness depends on the number of rollers in contact, which can vary according to the applied load. The relation between bearing deflection and the applied load is nonlinear. Burton et al. (2001) describes the bearings properties in more details.

The stiffness of the low-speed, the medial and the high-speed shafts and the safety coupling are presented as torsional springs.

Results and Discussions

Lagrange's equations are used to describe the movement of the obtained complicated dynamical system. In this case Lagrange's equations of motion are written as

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right)-\frac{\partial T}{\partial q}=-\frac{\partial L}{\partial q}-\frac{\partial F}{\partial \dot{q}}+Q,$$

where: q is the generalized coordinates, T and L are respectively the kinetic and the potential energy of the multibody systems, Q is the vector of the generalized external forces, F is the vector of the dissipative functions.

The expressions of the kinetic and the potential energy, of the generalized external forces and the dissipative functions are composed and determined in (Vukov and Bonova 2009, Todorov and Vukov 2009b, Todorov et al. 2007). Using these methods, the system of parametric differential equations describing the vibrations of the wind turbine can be obtained.

The linear parametric differential equations which are used to describe the behavior of the investigated system are

$$A(\omega t)\ddot{q}+\omega B(\omega t)\dot{q}+\left[C_m(\omega t)+C_\omega(\omega t)\right]q=Q(\omega t)$$

where: A is the inertia matrix, C_m is the mesh stiffness matrix, B is the gyroscopic matrix, C_ω is centripetal stiffness matrix, ω is the rotational speed of the rotor. The matrices A, C_m and C_ω are symmetric and B is skew-symmetric. Q is the vector of external loads.

This model allows creating of some variable loads on the system with the vector of the external loads Q depending from the work regimes.

The developed model of this kind of wind turbines can be used to study some dynamical processes in different specific work regimes of the same kind of wind turbines. Different extreme situations and unusual work regimes are modeled by using suitable formation of the vector of external loads. The vector of external loads allows investigating the influence of some typical groups of unchangeable loads.

I. Variable loads on the rotor caused by wind. Some regimes in variable windy conditions and high turbulence are modeled. The most favourable impact of the wind is accounted by 3D analysis of the wind for a definite zone. It is composed the function Q, which describes its characteristics. Thus in this dynamical model and composed equations is included the impact of the unchangeable loads from the wind on the rotor. Consequently it is possible to investigate the dynamical processes and the behavior of the wind turbine during such unfavorable conditions.

II. Variable loads caused by starting and stopping of the rotor. In fact starting and stopping of the rotor are unestablished regimes. These regimes, especially accidental stopping, cause extra dynamical loads in the whole construction. They can be accounted by introduction of the function Q, which depends on the mass, inertia and elastic characteristics of the construction.

III. Variable loads caused by passing through resonance regimes and working nearby these regimes. The passing through resonance regimes cannot be avoided during the exploitation of the wind turbine. Except starting and stopping of the rotor, the sudden change of the strength and direction of the wind can be a typical example for that. The offered model can help to definite and investigate the resonance regimes in advance. Then it can be possible to model the behavior of the system in different speed of passing through these regimes. The function Q which gives extra dynamical loads in these regimes is introduced.

IV. Variable loads from the generator. It is necessary to investigate the dynamical characteristic of the generator to obtain these loads. The influence of this dynamical characteristic on the behavior of the wind turbine is accounted by introducing of the relevant function Q.

Conclusion

The developed model of wind turbines can help to investigate dynamical processes in different specific work regimes of this kind of wind turbines. Suitable modeling of variable external loads gives some possibilities to investigate the behavior of the system in extraordinary situations and different work regimes. In this way it is possible to define some recommendations for more effective work of that kind of wind turbines.

Acknowledgements

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