A Simplified Model for Fatigue Load Calculations of Small Wind-Turbines with Vertical Axis of Rotation

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Abstract

Wind Turbines with a vertical axis of rotation (VAWT) recently regained new interest. In this paper we summarize results from [2] in which our new aerodynamic model [1] was applied to an existing 50 kW machine. The presentation is organized as follows: First we present our simplified model which was formulated in closest analogy along the rules from IEC 61400-2 used for horizontal axis wind-turbines including some rigid-body extensions. Second we shortly discuss the only to us known aeroelastic code for VAWT, GAROS. Finally we present our results for fatigue loads from application to an 50 kW (140 m² swept area) prototype from both computations. As a main result we see that the differences between our simplified model (rigid body model with most equations coming from engineering mechanics) and a full aeroelastic modelling seems to be largest for the beam system supporting the blades on the shaft.

1 Introduction

Investigations of wind-turbines rotating on a vertical axis have a long history. Starting in the 70ies as well in the USA, Canada and Europe several long-termed projects were launched to investigate the possibility to compete with wind-turbines rotating on a horizontal axis. Some advantages for VAWTs are:

- no wind-yaw system has to be included
- heavy parts of the drive-train may be put onto the ground

Contrarily several disadvantages have also to be named:

- Strongly transient and turbulent flow during each half of a revolution give raise to high fatigue loads
- wind-shear has a stronger influence if no tower is used (so called H-Darrieus)
- start-up devices have to be used.

Nevertheless the development culminated in the so-called *EOLE-C* a 100 m machine with 4 MW rated power. To reduce the fatigue loads significantly, the RPM had to be reduced. The measured peak-power therefore was not larger than 1.5 MW.

A summary - with emphasis on the American approaches - of all these early efforts was recently given in the book by Paraschivoiu [3].

Nowadays new interest stems from designers in connection of small wind-turbines. Unfortunately in [5] a simplified computational model is only given for wind-turbines with a horizontal axis of rotation. We here present a simple engineering model which was developed in the spirit of [5].

2 Definition of the model

First part is asuitable aerodynamic model for the axial induction a. We use from [6]:

$$a = \frac{Bc}{2R} \cdot \frac{R \cdot \omega_{Nenn}}{v_{Nenn}} |\sin \varphi|$$

With B = number of blades, c = chord, R = Radius of rotor, ω_{Nenn} = rated angular velocity and v_{Nenn} = rated wind speed. In additon φ is the local azimuthal position of the rotor. Clearly this model is only applicable for low-solidity ($\sigma = B\ c\ /2R \leq 0.3$) rotors. No internal iteration like for horizontal machines has to be performed. Is has to noted that without this model rather arbitrary values for cP and cT come out. A typical output is shown in fig 1. TSR is 1.5 and with σ = 0.25 we get cP = 0.25 and cT = 0.32.

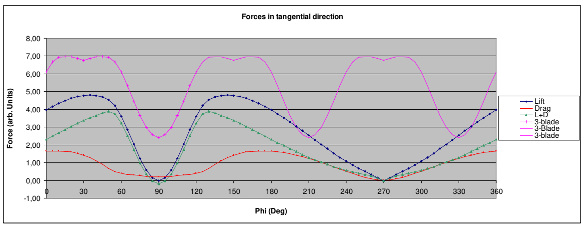

Fig. 1: Azimuthal vatiation of tangential forces of a three-bladed darrieus Rotor with straight blades with aerodynamic model from [6].

This model was checked against the BEM code for VAWTs from Strickland [7] and gave reasonable agreement.

The structural parts of the turbine were modelled from

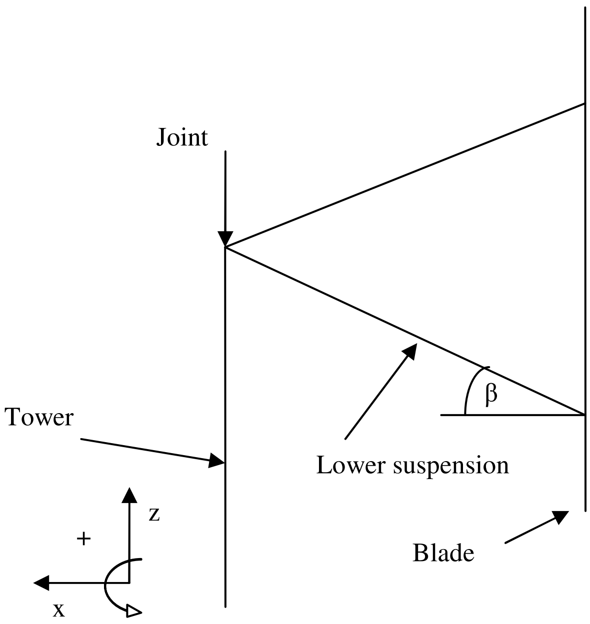

Fig. 2: Simple rigid beam model for blades with tower-connection. From [2].

simple formulares from engineering mechanics (see fig. 2). In addition an effective Young's modulus was calculated in case of GRP used for the rotor and blade suspension.
Main task was an estimation of load collectives for fatigue loads.

3 Example: A 50 kW VAWT

Our test case was a 50 kW Prototype which is of straight bladed Darrieus type and has 12 m rotor-diameter as well as 12 m blade length. This gives a total swept area of approx. 144 m². Rated windspeed is 12 m/s and rated RPMs are 50 per minute. Fig. 3 gives an impression of the Turbine.

Fig. 3: MARC-Vertikon-H50, Source: MARC Power GmbH.

4 Results

In this section results four typical simulation of production operation at rated wind-speed are presented:

- Production operation, no turbulence
- Production operation, 12 % turbulence
- Fully aeroelastic calculation with GAROS

a) Production operation, stationary model, no turbulence.

In a frist attempt, constant RPM operation, no rigid body effects and no inflow turbulence was modelled.
With this – oversipmlified modelling – (Fig. 4) we see (x-axis: design stress, y-axis: lifetime) that depeding material's quality the lifetime of blade and suspension can be very different.The results suggest a stress level where both stuctures have equal liftimes

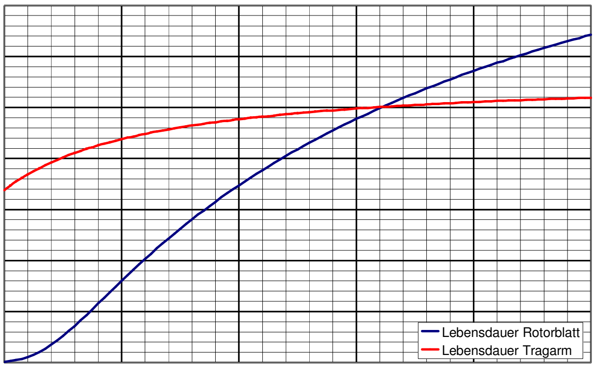

Fig. 4: Sample result for life-time of blade(red) and suspension (blue). From [2].

b) Production operation with 12 % turbulence

The regulations give a clear description how the transient behaviour has to implemented into design load cases (DLC). Therefore we decided to implement a simple rigid body model which allows for rigid body effects due to varying RPM. This clearly is induced by variying inflow windspeed. For a rigid body with fixed axis of rotation we can write [2]:

$$\sum M_i = \ddot{\varphi} \cdot J_0 = F_T \cdot R + M_{Gen} + M_{Brems}$$

Here F_T summarizes the input for the aerdynamic forces.

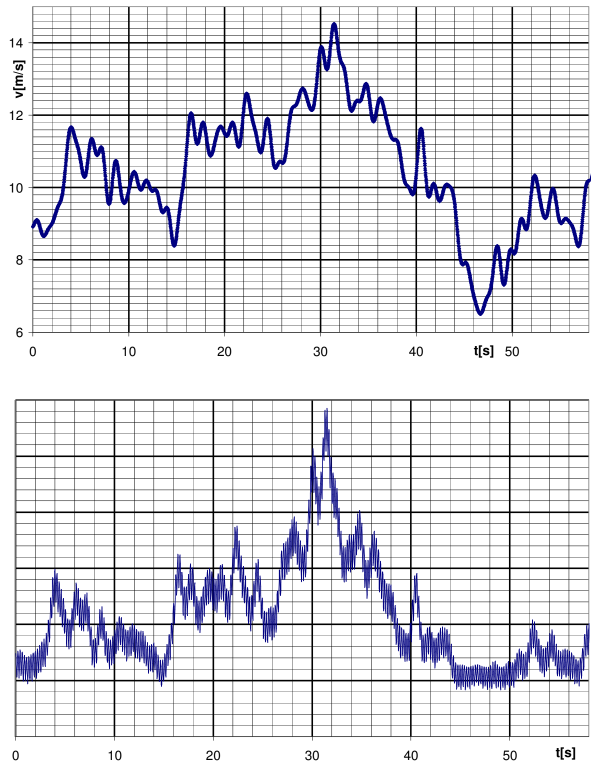

Fig. 6: Windspeed (above) and corresponding moment at shaft From [2].

c) Fully aeroelasitc calculation

In addition to the fully aeroelastic code GAROS [4] was used to validate our simply rigid-body model. GAROS was mainly developed by A. Vollan, starting in the 70ies, for application of generic darrieus turbines like ÈOLE-C and Dornier's advancements . It includes: elastic beam modelling of the structure, gyroscopic effects due to a 2nd order formulation and aerodynamic forces (quasi-static and transient) in form of a state-of-the-art BEM formulation.

First a stability analysis was performed. As an outcome a Campbell-diagram is produced including an estimate of aerodynamic damping. Below 50 RPM no possible resonances were found and the aerodynamic damping always was sufficiently negative in the order of 3 %.

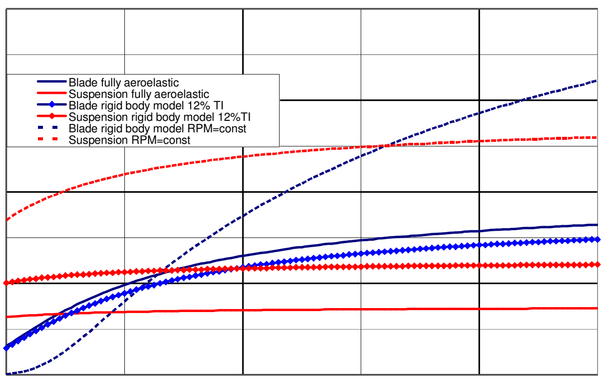

Fig. 7: Sample results from a comparison of different methods for life-time of blade(red) and suspension (blue) as function of the strength of the material. From [2].

Fig. 7 gives a comparison for the estimated life-times from our three different approaches. For the blades the differences between aeroelstic and rigd-body simulaiton are small, whereas for the suspension a significant difference was found. Clearly the influence of turbulence is visible.(dotted lines).

It has to be noted that during evaluation of GAROS some inconsistencies were found, esp. for displaying rotor-averaged loads.

5 Summary and Conclusions

For load estimation of small wind vertical axis wind turbines a simple rigid-body model has been developed and checked against the only available aero-elastic BEM code GAROS.

The wind-turbine tested is a 50 kW Prototype with approx. 140 m² swept area.

The overall performance of our model seems to be in reasonable agreement with GAROS. It has to be noted that the exact numbers of power-outcome and loads heavily rely on the aerodynamic model for the axial (wind-speed direction) induction. At the moment the model of [6] has been implemented only. No iteration for reaching equilibrium of axial momentum balance has to be performed. This seems to indicate that only lightly loaded turbines ($\sigma < 0.3$) are able to be modelled properly. Because the rigid-body-model was developed within a spread-sheet environment is has the well-know shortcomings. Therefore a platform-independent version seems to be desirable.

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Acknowlegdements

The authors wish to thank Dr.-Ing. M. Pfalz, FiberTec-Products GmbH, Chemnitz and Mr. R. Caliebe, MARC Power GmbH, Bremerhaven for providing them with all necessary information. This project was funded by CEwind, Schleswig-Holstein's Centre of Excellence for Wind-Energy.