DESIGN, FABRICATION AND VERIFICATION TESTING OF THE WIND TURBINE ROTOR BLADES FROM COMPOSITE MATERIALS

Bosko P. Rasuo*, Aleksandar Dj. Veg*
***University of Belgrade, Faculty of Mechanical Engineering, Belgrade**

Keywords: *Composite materials, Wind turbine rotor blade, Verification testing*

Abstract

In this paper the design, fabrication and analysis of behavior by full-scale verification testing for the wind turbine rotor blade of composite laminated materials is given.

The verification test program for the wind turbine rotor blade encompassed static and dynamic testing. The static tests of the blade involved experimental evaluation of torsional and flexional blade stiffness and its elastic axis position. Dynamic tests involved testing of vibratory characteristics and testing of blade fatigue characteristic. In structural vibration tests natural frequency, vibration modes and damping ratio for the structure were measured. The fatigue analysis of the structure of blade root section was performed after fatigue test cycles for detection of laminate separation, tolerance and distortion of crossections of structure.

1 Introduction

In general, high-performance composites exhibit high strength and stiffness, low density, and good resistance to fatigue and corrosion, properties that make them very well suited too many wind energy and aerospace applications. The use of fiber-reinforced composites in critical structures in wind energy is growing rapidly. But, the introduction of composites has not been without problems. These include development of entirely new design, fabrication, and qualification discipline, difficulty in analyzing internal stresses, demonstrating this technology to certifying agencies, determination of adequate test criteria, and quantifying environmental degradation. The development and qualification of the wind turbine components and system includes a heavy emphasis on a full-scale test approach independent from the design process. In the case of fatigue-loaded wind-critical components, a laboratory fatigue program is conducted, supported by static and vibratory tests, stress surveys and coupon or subelement programs.

2 Status of Wind Energy Standards

On a global level the International Electro-technical Committee (IEC), and on a European level CEN and CENELEC (1995) provide working platforms. Reliable standards are essential in the reduction of uncertainties or risk, particularly from the point of view of insurers and financiers of wind energy projects. Certification of wind turbines or components is state-of-the-art and a must in most places around the world. Furthermore certification to harmonized requirements is an active support of export. Therefore it is important for manufacturers, banks and insurances of wind turbines and components to know the different certification processes as well as guidelines. The procedures to obtain Type and Project Certificates are described on the basis of IEC WT01: IEC System for Conformity Testing and Certification of Wind Turbines, Rules and Procedures, 2001. Type Certification comprises Design Evaluation, Manufacturing Evaluation, Evaluation of Quality Management and Type Testing. Project Certification is based on Type Certification and covers the aspects of Site Assessment, Foundation Design Evaluation and Installation Evaluation. Certificates are issued upon the successful completion of the relevant Type Certification and Project Certification. A number of wind energy standards have been published, mostly under the Committee of IEC and gives an overview of the publications as of mid 2005 [1-3].

Current status of wind turbine standardization area is for design requirements: 1- Wind Turbines IEC 61400-1; 2- Small Wind Turbines IEC 61400-2: 3- Offshore Wind Turbines IEC 61440-3, and 4- Gear Boxes for Turbines from 40 kW to 2 MW and larger ISO/IEC 81400-4; requirements for measurements: 1- Acoustic Noise Measurement Techniques IEC 61400-11: 2- Wind Turbine Power Performance Testing IEC 61400-12; 3- Power Performance Measurements of Grid Connected

Wind turbines IEC 61400-12-1; 4- Mechanical loads IEC TS 61400-13; 5- Declaration of Apparent Sound Power Level and Tonality Values IEC TS 61400-14; 6- Power Quality Characteristics of Grid Connected Wind turbines IEC 61400-21, and 7- Full-scale Structural Testing of Rotor Blades IEC TS 61400-23; and other standardization area: 1- Lightning Protection IEC TR 61400-24; 2- Communication for control and monitoring IEC 61400 -25; 3- IEC System for Conformity Testing and Certification of Wind turbines IEC WT01; 4- Protective Measures EN50 308; 5- Electromagnetic Compatibility prEN 50 373; 6- Declaration of Sound Power Level and Tonality Values prEN 50 376, and 7- International Electro-technical Vocabulary, Part 415 IEC 60050-415.

3 Design, Fabrication and Verification Testing

A development of a wind turbine rotor blades (Rated power: 0.85 MW, rotor diameter: 52 m, swept area: 2,124 m^2 and specific rating: 0.400 kW m^{-2}, [3]) was performed in four phases: (1) the blades design on the PC computer using CATIA designing system (Figures 1 and 2), (2) preparation and cutting of blade components on the Gerber-Garment cutting system (Figure 3), (3) blade manufacturing in a two-section die (Figure 4), and (4) final verification testing. In the blade manufacturing procedure the conventional composite materials with epoxy resin matrix, a fiberglass filament spar, a ten-section skin of laminated fabrics, some carbon filament embedded along the trailing edge and core were used.

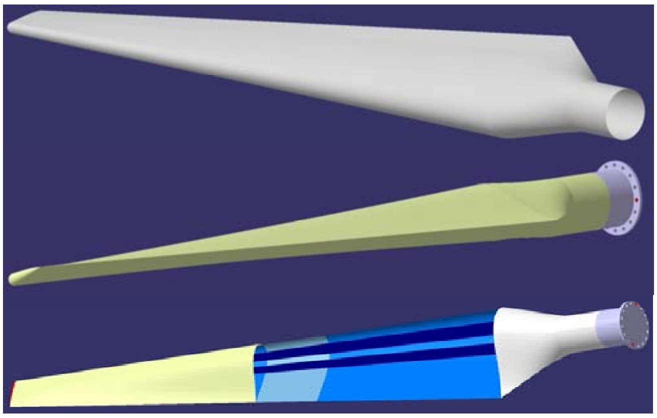

Fig. 1. Blade solid model, blade aerodynamic solid model and the main spar of the blade (CATIA)

The verification test program for a wind turbine rotor blades encompassed static and dynamic testing (IEC TS 61400-23).

Fig. 2. Tubular tower (Upwind type)

Fig. 3. Automated Gerber-marker making system

The static tests of the blade involved experimental evaluation of torsional and flexional blade stiffness, elastic axis position of the rotor blade, verification of buckling stability and failure beyond limit load is recommended but not required. Dynamic tests involved testing of vibratory characteristics and verification testing of blade fatigue properties (see Figure 5). The aim of the rotor blade vibratory testing program was to determine the blade main aeroelastic properties. The program included determination of the natural oscillation modes and the structure's natural frequency and also evaluation of blade structural damping. The logarithmic decrement of the free vibrations was utilized to characterize the structural damping of blades. Q-factor is also usually used to define the structural damping and gives relative energy reduce in successive oscillations. The fatigue test program of the blade included: interlaminar separation (delamination) testing and geometric deformation of the blade cross-sections following the fatigue test program during which real rotor blade loads where simulated - the same loads to which blade is exposed under extreme wind-conditions (2% from life time). The homological fatigue testing program for the blade root involved, conforming to the standards, fatigue testing of one blade [1-11].

Fig. 4. Matched composite die

Verifies the blade's ability to withstand the operating loads for a full design life, 30 year life > 5 x 10^8 cycles applied with accelerated load history from 1 to 10 million cycles (approximatively 2% from life time), required by IEC-61400-23 and IEC WT01. The load applied on one or two axes (flapwise and edgewise direction) and the load methods vary among laboratories.

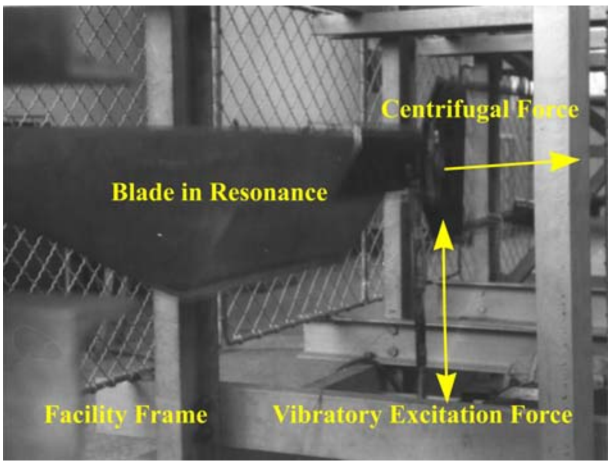

Fig. 5. Rotor blade in fatigue testing

4 Conclusion

Wind turbine blades are becoming bigger and increasingly more complex, with a wide variety of materials and manufacturing techniques being utilized in their construction. The new blade rules provide detailed guidance and interpretation throughout the blade development program to meet the safety requirements of the internationally accepted IEC WT-01 certification scheme.

Composite materials in particular are used extensively in modern wind turbine design and the complexity of structural substantiation will increase with increasing turbine size and structural optimization. In order to manage this, one must use the experience from the aerospace composites industry and recommended the widely accepted building block approach to composite structural substantiation that is based on iterative testing and analysis to achieve confidence in the final design.

5 References

[1] Prepared by EWEA, Strategic Research Agenda of the Wind Energy Sector 2020, 2005, EWEA.

[2] Tadich J. K., et al, New Guidance for the Wind Turbine Blades, Copenhagen Offshore Wind 2005, Copenhagen.

[3] Rasuo B., Verification Testing of the Wind Turbine Rotor Blades from Composite Materials in Designing Process, Materials Congress 2006, London.

[4] M. Woebbeking, A. Andreä and A. Dombrowski, Wind Turbine Certification and Type Certification IEC WT 01: IEC System for Conformity Testing and Certification of Wind Turbines, 2001-04, Germanischer Lloyd WindEnergie GmbH.

[5] F. Bertagnolio et al, Wind Turbine Airfoil Catalogue, RISØ-R-1280 (EN), Risø National Laboratory, Roskilde, Denmark, 2001.

[6] D. A. Griffin, Blade System Design Studies Volume I: Composite Technologies for Large Wind Turbine Blades, SAND2002-1879, 2002, Kirkland, Washington.

[7] D. A. Griffin and T. D. Ashwill, Alternative Composite Materials for Megawatt-Scale Wind Turbine Blades: Design Considerations and Recommended Testing, AIAA-2003-0696

[8] W. Musial Wind Turbine Testing and Certification, Wind Turbine Blade Workshop, 2004, Albuquerque, NM.

[9] G. Bir and P. Migliore, Preliminary Structural Design of Composite Blades for Two- and Three-Blade Rotors, NREL/TP-500-31486, 2004, National Renewable Energy Laboratory, Golden, Colorado.

[10] E. R. Jørgensen et al, Full scale testing of wind turbine blade to failure - flapwise loading, Risø-R-1392(EN), 2004, Risø National Laboratory, Roskilde.

[11] M. J. Sundaresan, M. J. Schulz, and A. Ghoshal, Structural Health Monitoring Static Test of a Wind Turbine Blade, National Renewable Energy Laboratory, NREL/SR-500-28719, 2002.