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THE DESIGN OF A TEST BENCH FOR WIND BLADES BENDING WITH SMALL DIMENSION

IoanCurtu, Mariana D.Stanciu, RareșȚițeiu, TeodoraSturzu
Transilvania University of Brasov, Department of Mechanical Engineering, Brasov, Romania, ,
curtui@unitbv.ro, mariana.stanciu@unitbv.ro,sturzu_teodora@yahoo.com,

Abstract:*The paper presents the design stages of a bench to test wind blades with small dimensions and its verification from the point of view of stresses and the deformations of test bench for five loading cases of the blade. Thus, following a thorough research in the state of the art literature regarding the types of stands used to test the blades, the possibility of the reconversion of a stand from the strength of materials laboratory in the Mechanical Engineering Department, and its adjustment for bending tests have been analyzed. Several versions of the bench have been designed, and the optimum version has been chosen depending on strength, stability and economical accessibility. Bending tests have then been performed by means of finite element analysis. Consequently, the proposed stand meets the design requirements.*
Keywords:*bending, bench design, reconversion, finite element analysis*

1. METHODS AND SYSTEMS TO TEST WIND BLADES FOR TURBINES

The aerodynamic phenomena developing around the blade have effects of utmost importance regarding the tensile and strain stages. Compound stresses appear as consequences of aerodynamic forces that have a cyclic variation with the change induced in the position of the blade through revolution as well as in time, depending upon the wind pressure variations [1, 2]. At the level of the aerodynamic blade a lift force and a drag force perpendicular to the lift force develop. During revolution motion, a centrifugal force is present, force that tends to create stress on the length of the blade (Fig. 1).

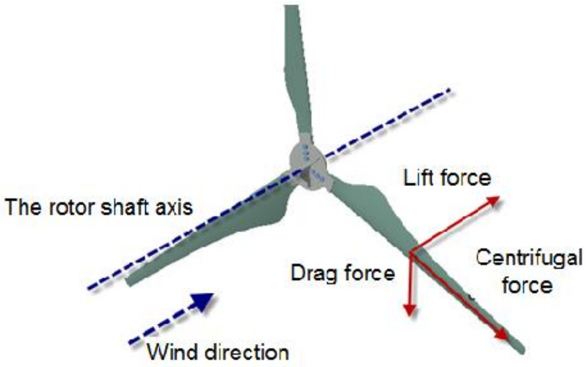


Figure 1: Types of forces that load the blades in wind turbines

The blade of a wind turbine is the most important component, which is tested to static and dynamic (fatigue) stresses. The results of these tests are useful when improving the shape and the efficiency of the blade, the production technology, to monitor the stages of the stresses and strains developed insinde the blade [1]. Testing the blades to fatigue has the purpose to identify the flaws of the model, as well as to find the functioning period of the blade. During the aerodynamic tests, cycles varying between 1 and 5 millions are applied, and the loadings are applied on two main directions, whose values are lower than those in case of static tests. For static tests, the loadings are applied in a single direction in order to determine the maximum stress inside the blades. This test may be destructive or nondestructive. In the stand in figure 1, a, the blade is fixed in the testing stand under a certain angle, due to the appearance of high strains of the blade during testing [1, 3, 4]. A method used often is the application of the force by means of weights in various areas on the blade (fig. 1, b). The experience of the researchers has proven that the usage of a hydraulic system to apply the force is expensive for wind blades having very large dimensions (over 15 *m*). Generally, in order to diminish the risk of damaging the surface of the blade's profile, for static tests, the blades are fixed in profiles which copy the profile of the blade.

a) b)

Figure 2: Static testing stand for blades of large dimensions: a) application of the force by means of weights; b) application of the force by hydraulic actuators [1]

The methods to monitor and determine the structural integrity of the blades in wind turbines are based on modern technologies which prove relevant depending on the type of the investigation (laboratory conditions – in vitro, semireal conditions – in situ or real conditions – in vivo) as following:

a) In vivo methods: *Imagistica AirScan with drones* with which flaws from the visible spectrum (possible cracks, exfoliations of the protective layer, areas of impact with birds, areas affected by electricity), flaws from the infrared spectrum (possible structural flaws undetectable in visible spectrum) are detected.

b) In situ methods: The *DashWin System* which consists in an automatic system including an advanced unit of inspection by shearography and a platform for robotic positioning. The inspection system offers a fast, safe inspection, without any contact, of the blades in wind turbines for flaws present on the surface and under the surface, but in the immediate vicinity of the surface. The robotic platform allow a systematic inspection, „in situ", of the whole blade of the wind turbine and without the risks implied by an inspection engineer working at heights.

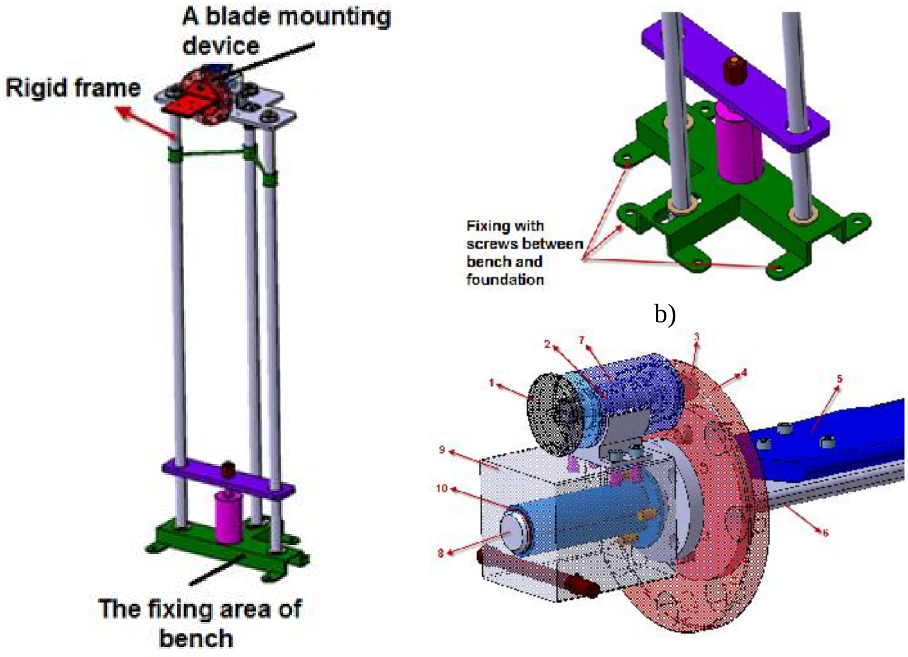
c) In vitro methods: a system of sensors based on Fiber Bragg Gratings (FBG); a transmission system – ultrasonic reception; thermography system; pulse-echo; radiography; acoustic emissions etc.

Grasse (2011) investigated the aspects of the integrity of the blade's material by simulating the dynamic loadings on two directions and by measuring the strains, the own frequency and the response of the structure to forced virbations, after which identifying the flaws areas by means of a sensors network [4]. Hiromasa (2008) suggests as an investigation method the usage of an aerodynamic tube which could simulate the action of the wind at a scale proportional to the dimensions of the turbine, having as purpose the determination of the stresses inside the blades in turbines due to the action of the wind [6].

2. THE DESIGN OF THE EXPERIMENTAL STAND

Considering the previously presented studies, several options of experimental stands have been designed, starting from the following criteria: the dimensions of the part to be tested; the easy handling of the stand, as well as of the blade during the tests; the strength and stiffness in order to eliminate the measuring errors; attractive shape and aspect; low costs (by recycling the out of use stands) [7,8 9]. Thus, the stand in figure 3 has been designed, including the following components: the fix frame of the stand (Fig. 3, a), the fixing area for the foundation (Fig. 3, b) and the fixing area of the blade (Fig. 3, c).

The fixing device of the blade is designed such that, by action of the button 1, the connecting element 2 realizes a translation on the shooting direction. The wedgewelded on the connecting element is removed from wheel 4, such that the blade 5 placed on the support 6 may rotate from 15 to 15 degrees. The revolution – blocking system of the blade reaches the initial position by spring 7. The blade is manually rotated by the operator. The revolution is realized through flange 8 which is introduced inside block 9 and fixed by the zeger ring 10. In order to load the blade 1 with a certain force, the abrasive rubber element 2 has been designed to cover the blade. The hook and the pan 3 are mounted on the rubber element, on which the weights will be fixed.



b)

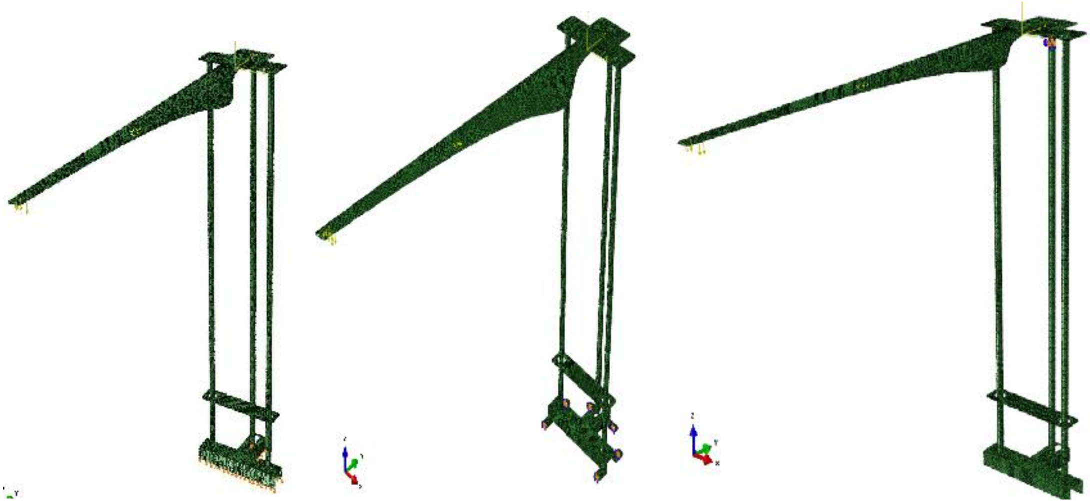
a) c)

Figure 3: The main parts of testing bench

3. THE VALIDATION OF THE DESIGNED MODEL BY MEANS OF THE FINITE ELEMENT ANALYSIS

3.1. Input data

In order to verify the stresses and strain states of the designed stand, the model has been simplified and the main stress producing elements have been chosen. The material from which the stand is made of is OLC 45, having the following physical-mechanical properties in conformity to STAS 880-80: density ρ=7800 *kg/m*^{3}; elasticity modulus E=2.1E5 *MPa*; Poisson coefficient ν=0.3; allowable tensile strength σ_a=150 *MPa*; ultimate tensile strength σ_r=620 *MPa*; yield stress $\sigma_{0,2}$=340 *MPa*. From the outline point of view, three cases have been studied: the support of the stand (Fig. 4, a); fixing the stand into the foundation (Fig. 4, b) and fixing the stand in both the foundation and onto a vertical wall in the upper part (Fig. 4, c). For each case, the stands were analized for the bending of the blade as consequence of the application of the forces at the free end, having the following values: 1; 10; 50; 100 and 300 *N*.



a) b) c)

Figure 4: Options to analize the stand in various outline conditions: a) the supporting of the stand (case 1); b) fixing the stand into the foundation (case 2); c) fixing the stand in both the foundation and onto a vertical wall in the uppert part (case 3)

The meshing of the structure has been realized such that, in the areas of interest, the dimensions of the finite elements are smaller and the area having stress concentration is sharply meshed (Fig. 5). The translation from the areas of finite elements of small dimensions to those with large dimensions has been made progressively. Planar elements of type shell 2D having dimensions of 5 *mm* have been used, because the actual model mostly includes elements having two dimensions much larger than the third 5 *mm*.

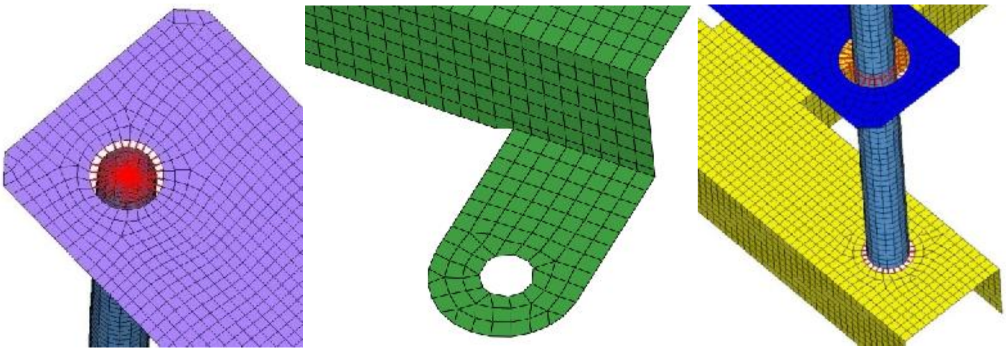


Figure 5: The meshing of the structure in areas having tension concentrators

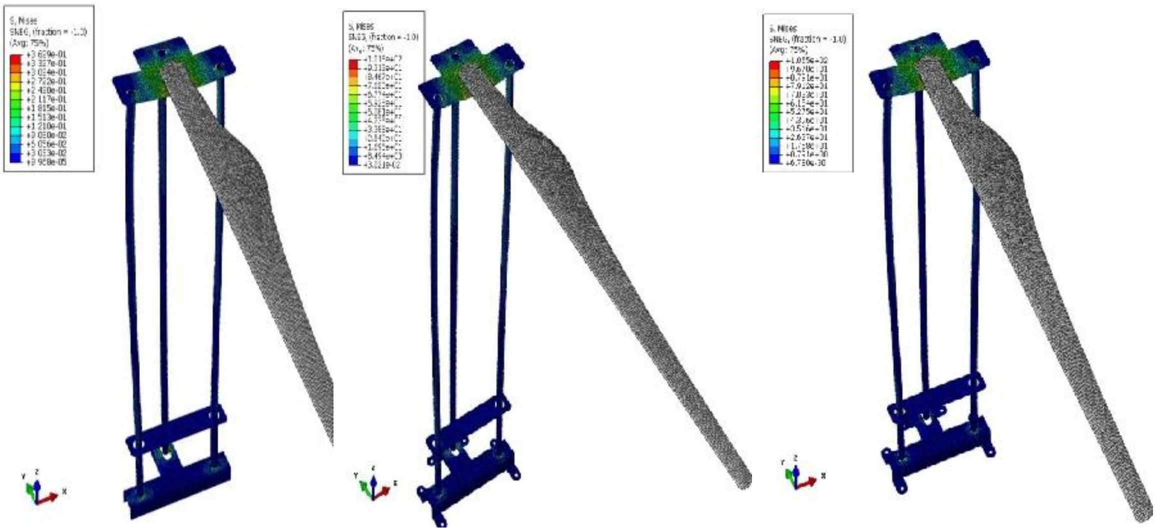
3.2. Output data

After running the ABAQUS program, multiple numerical and graphical results were obtained, all of which are presented in tables 1, for each value of the intensity of the applied force.

Table 1: Centralization of the FEM results considering the displacements

Case	Force *N*	Total displacement *mm*	Displacement on the X axis*mm*	Displacement on the Y axis*mm*	Displacement on the Z axis*mm*	Total revolution *rad*	Revolution on X axis*rad*	Revolution on Y axis*rad*	Revolution on Z axis*rad*	Von Misse Tensions *MPa*
1	1	2.28E-02	2.23E-03	2.94E-03	8.67E-04	1.75E-05	1.56E-05	1.16E-05	8.24E-07	3.63E-01
	10	2.28E-01	2.23E-02	2.94E-02	8.67E-03	1.75E-04	1.56E-04	1.16E-04	9.24E-06	3.629
	50	1.141	1.11E-01	1.47E-01	4.33E-02	8.76E-04	7.82E-04	5.79E-04	4.62E-05	18.14
	100	2.30E+00	2.24E-01	2.96E-01	8.72E-02	1.76E-03	1.57E-03	1.16E-03	9.29E-05	36.49
	300	6.911	6.74E-01	8.91E-01	2.63E-01	5.30E-03	4.74E-03	3.51E-03	2.80E-04	109.9
2	1	2.28E-02	1.46E-03	7.23E-06	8.61E-04	1.73E-05	1.53E-05	1.16E-05	1.98E-07	3.36E-01
	10	2.28E-01	1.46E-02	7.23E-05	8.61E-03	1.73E-04	1.53E-04	1.16E-04	1.98E-06	3.355
	50	1.142	7.31E-02	3.62E-04	4.30E-02	8.64E-04	7.67E-04	5.80E-04	9.89E-06	1.68E+01
	100	2.30E+00	1.47E-01	7.27E-04	8.65E-02	1.74E-03	1.54E-03	1.17E-03	1.99E-05	33.74
	300	6.92E+00	4.43E-01	2.19E-03	2.61E-01	5.23E-03	4.64E-03	3.51E-03	5.99E-05	101.6
3	1	1.95E-02	1.37E-03	3.57E-03	7.20E-04	1.55E-05	1.35E-05	1.10E-05	2.15E-07	3.48E-01
	10	1.95E-01	1.37E-02	3.57E-02	7.20E-03	1.55E-04	1.35E-04	1.10E-04	2.15E-06	3.484
	50	9.76E-01	6.87E-02	1.78E-01	3.60E-02	7.75E-04	6.74E-04	5.47E-04	1.08E-05	17.42
	100	1.96E+00	1.38E-01	3.59E-01	7.24E-02	1.56E-03	1.36E-03	1.10E-03	2.16E-05	35.04
	300	5.91E+00	4.16E-01	1.08E+00	2.18E-01	4.69E-03	4.08E-03	3.32E-03	6.51E-05	105.5

From the map of the tensions and displacements obtained with FEM one may observe that the highest tensions are recorded in the fixing area of the blade into the testing stand, no matter the outline conditions imposed in the modeling (Fig. 6). A stressed area is also found at the joint between the pillars onto the lower plate of the stand. From the displacements' point of view, these reach maximum values at the top of the blade. Another area to develop total displacements and revolutions is found in the lower part of the stand in case 1 of supporting (Fig. 7).



a) b) c)

Figure 6: Distribution of Von Misse tensions

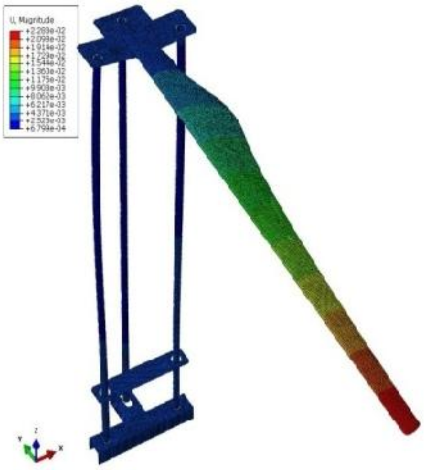


Figure 7: Distribution of the total maximum displacements in case 1

The intensity of the loading force influences the modulus of the tensions inside the structure of the experimental stand, yet their values is lower than the value of the allowable tensile strength of the stand’s material, as it may be observed in figure 8.

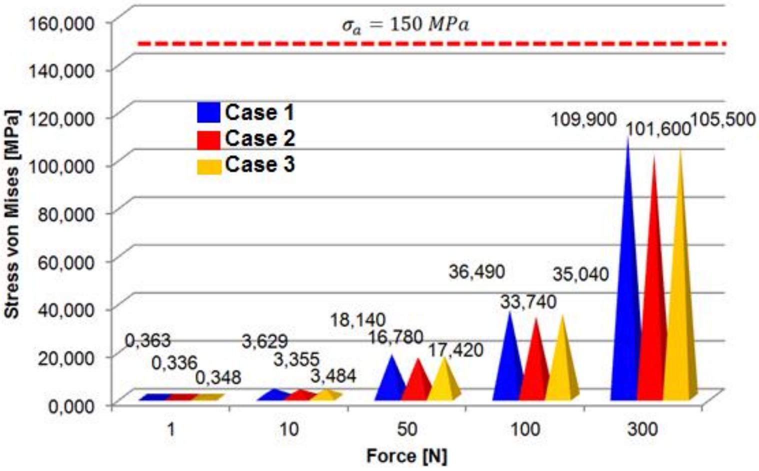


Figure 8: The variation of the tensions in the structure of the stand depending on the intensity of the loading force

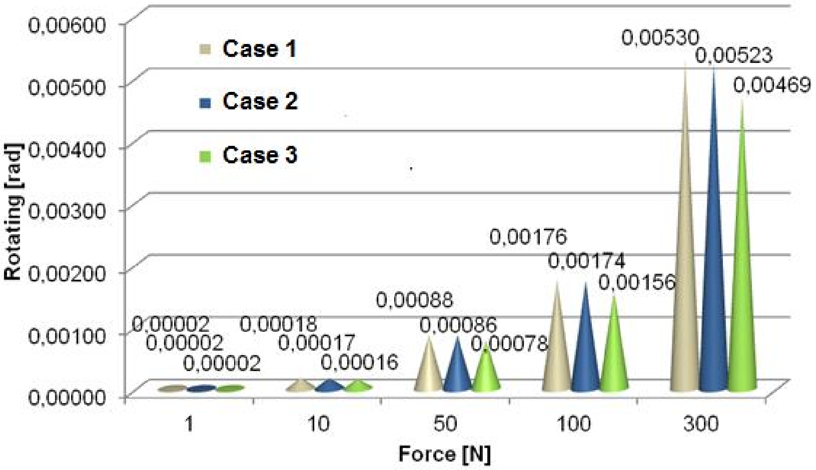


Figure 9: The variation of the revolutions inside the structure of the stand depending on the rise in the intensity of the loading force.

3. CONCLUSION

The experimental stand used to test the blades in the wind turbines of small dimensions must satisfy the stiffness and resistance requests, such that the results of the experimental measurements are not distorted. The concept of the stand was based on a research regarding the state-of-the-art literature, on the analysis of the tension and strain states, on the measurement capacity, on the interchangeability of the parts and on the costs. After the investigations, it has been proven that the best options are those regarding the fixing of the stand in both the foundation and on a vertical wall (pillar). The FEM analysis has been accomplished with a force of estimated value 300 *N*, this value also including the weight of the blade.

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