Modal analysis of a small vertical axis wind turbine (Type DARRIEUS)

Ion NILA*[,1], Radu BOGATEANU[2], Marcel STERE[1], Daniela BARAN[2]

*Corresponding author
*[,1] Aerospace Consulting, B-dul Iuliu Maniu 220, Bucharest 061126, Romania
inila@incas.ro
[2] INCAS - National Institute for Aerospace Research "Elie Carafoli"
B-dul Iuliu Maniu 220, Bucharest 061126, Romania
unquradu@gmail.com, dbaran@incas.ro

DOI: 10.13111/2066-8201.2012.4.2.9

Abstract: *This paper reports a brief study on free vibration analysis for determining parameters such as natural frequencies and mode shapes for vertical axis wind turbines (VAWT) for an urban application. This study is focused on numerical work using available finite element software. For further understanding of the wind turbine dynamic analysis, two vibration parameters of dynamic response have been studied, namely natural frequencies and mode shapes.Block Lanczos method has been used to analyze the natural frequency while wind turbine mode shapes have been utilized because of their accuracy and faster solution. In this problem 12 modes of structure have been extracted.*

Key Words: *Wind action, Vertical Axis Wind Turbine, Darrieus rotor, finite element commercial package, mechanical vibrations, modal analysis, natural frequencies, mode shapes, eigenvalue, Lanczos method*

1. INTRODUCTION

1.1 Preliminary considerations

The aim of the dynamic analysis is to determine the predominant natural frequencies and mode shapes of a structure. The overall integrity of a structure can be monitored by a regular measurement of the natural frequencies because, in general, structural damage of an element is reflected in the reduction of its stiffness.

1.2 Nomenclature

Airfoil section	NACA 0012
C	blade chord (= 200 mm)
C_L	lift coefficient
C_D	drag coefficient
H	blade span (= 3.6 m)
N_b	number of blades (= 5)
R	radius (= 3 m)
V	wind speed

2. SHORT DESCRIPTION OF THE WIND TURBINE

This type of turbine consists of five blades mounted vertically on a rotating shaft (fig.1). The shaft is fitted with two bearings that allow free rotation and torque transmission. Ten aluminum arms which support the five blades are joined to this shaft. The blades are made of fiber-glass coated foam and they are the key driving component of the turbine. The investigated structure is a guyed tower built from a lot of pipes attached to the ground by four guy cables (see fig.1).

For VAWTs – optimal blades are untwisted and they have a uniform cross section making them relatively easy to manufacture.

The guyed tower is held upright with guy cables which stretch from the tower to their anchors in the ground some distance (10 m) away from the base to the tower. A guyed tower is the least expensive system

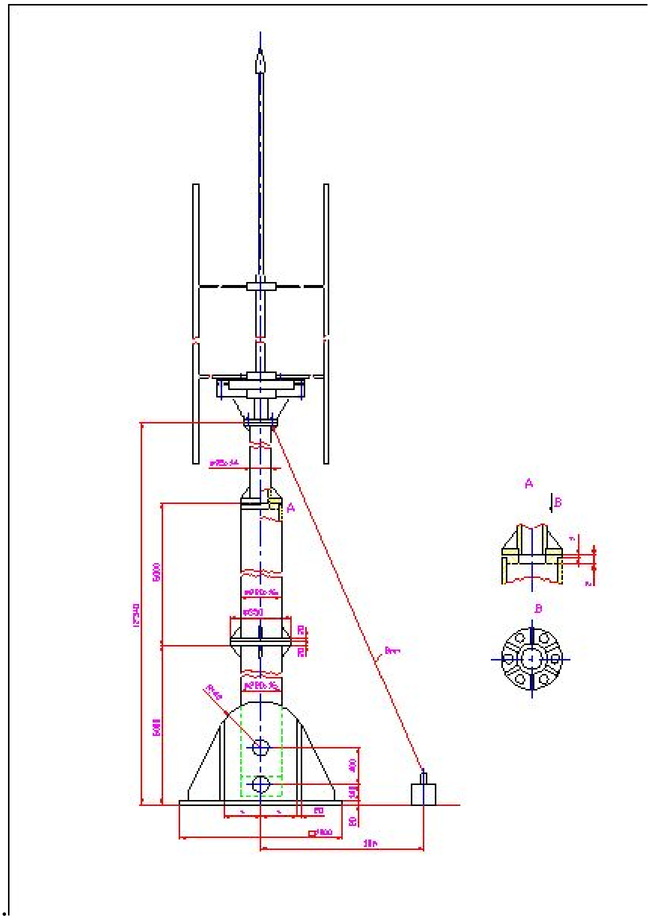

Fig. 1 The major components of the VAWT Darrieus_INCAS_2011

3. MODELLING

In the FEM model created for ANSYS run we used the following finite elements: PIPE16 (for tower), BEAM4 (for blades and arms), LINK 10 (for guy cables) and MASS21 for lumped masses.

The sketch of the model is shown in figure 2. Extensive FE model simplifications had been applied in the analysis processes to ease the result validity check. The used elements allow the user to gain a feel for analysis to anticipate what the results will be and to access the effects of the change of any parameter defining the structure.

The properties of materials are linear. The typical solutions with these properties require only a single iteration. A linear model analysis is a good approximation of the real behavior of the structure.

The stiffness distribution is important in static analysis whereas for dynamic analysis the mass distribution is the most important.

Getting the mass and mass density into the correct units is important when performing any form of vibration analysis. In this analysis SI units are used for material and sectional properties.

*** MASS SUMMARY BY ELEMENT TYPE ***

TYPE	MASS
1	412.510
2	64.4041
4	22.9458
5	99.0877
6	6.21496
7	3.88800
10	150.000
11	20.0000

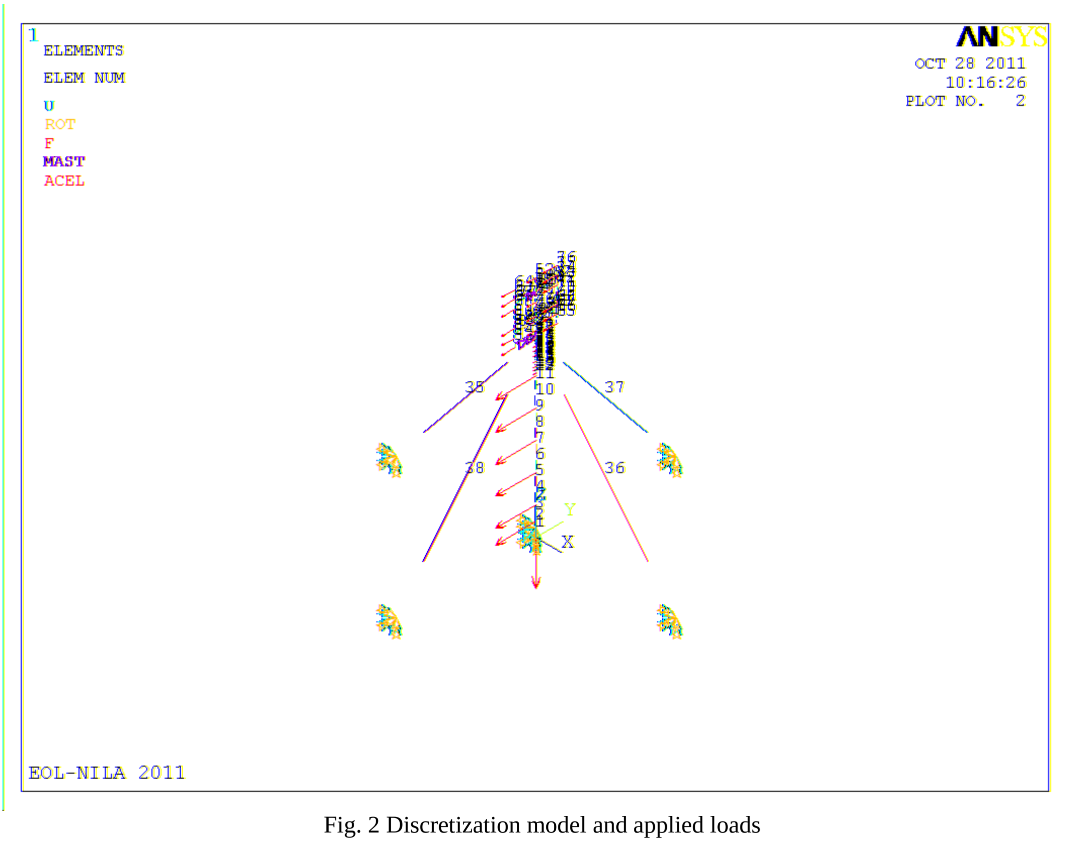

Fig. 2 Discretization model and applied loads

Wind load calculations were founded on the assumption of solid frontal areas of the blades and the tower structure. The aerodynamic loads were used as the design loads because they produce the largest forces on the blade. Also, the von Mises theory is a conservative predictor of the failure.

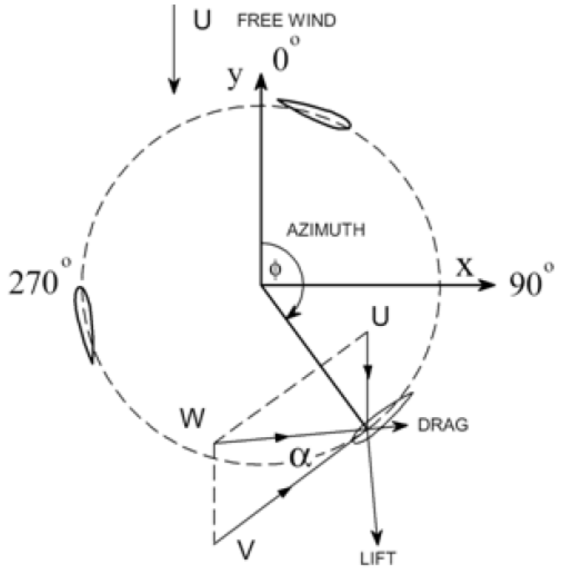

Fig. 3 Illustration of Darrieus concepts

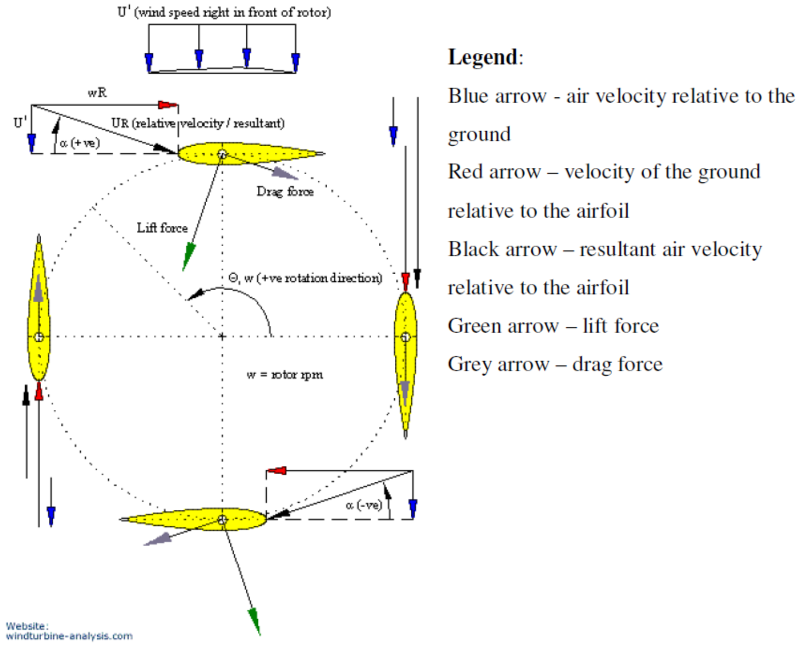

Fig. 4 Top views of forces on a Darrieus blade throughout 360 degrees of rotation [18]

In figure 4 is shown a top view of forces on a Darrieus blade through 360º of rotation (winturbine-analysis.com).

The double arrow represents the air velocity relative to the ground. The red arrow symbolizes the velocity of the Airfoil relative to the ground and the black arrow, the resultant air velocity relative to the airfoil [15].

The materials used are: steel for tower and guy cable, E-glass-epoxy for blades and aluminum alloy for blade arms. [1].

4. MODAL ANALYSIS

Modal analysis was used as analysis method for the linear elastic dynamic problem. Modal analysis is used to determine the model properties of a structure such as natural frequencies and mode shapes corresponding to the assumed geometrical and material properties.

This is an eigenvalue analysis and it is the undamped force vibration response of a wind turbine structure caused by an initial disturbance from the static equilibrium position.

This solution derives from the general equation by zeroing the damping and applied force terms.

The equation which must be solved is:

$$([K]-\lambda[M])=0 \tag{1}$$

where: $[K]$ - is the stiffness matrix (a square matrix of order equal to the number of degrees of freedom in the entire structure);

λ - is the eigenvalue;

$[M]$ - is the mass matrix

Mode shapes are normalized to the maximum displacement of the structure. Only the first few (5-6) eigenvalues of the model are interesting and physically meaningful. Since the finite element model is an approximation of the structure, than the higher eigenvalues and vectors are inaccurate.

The finite element model is created as normal within Prep7 and saved prior to enter the solution phase (/SOLU).

The analysis type is selected by using the MODOPT command. For the purposes of this study, the Subspace iteration method of Eigen solution was utilized and the solution is executed using the SOLVE command.

After the completion of the solution (FINI), the solution is re-entered (/SOLU) and the expansion pass is started (EXPASS, ON) where the number of modes to be expanded is entered (MXPAND, number = 5).

Expansion is executed using the SOLVE command.

Post-processing is performed in the usual manner and each frequency is stored using the SET command.

In this modelling the effect of temperature is neglected.

INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	0.70926	1	1	1
2	0.72527	1	2	2
3	2.9747	1	3	3
4	2.9965	1	4	4
5	5.5065	1	5	5
6	5.5517	1	6	6
7	7.7053	1	7	7
8	7.9534	1	8	8
9	8.2672	1	9	9
10	12.358	1	10	10
11	16.357	1	11	11
12	16.798	1	12	12

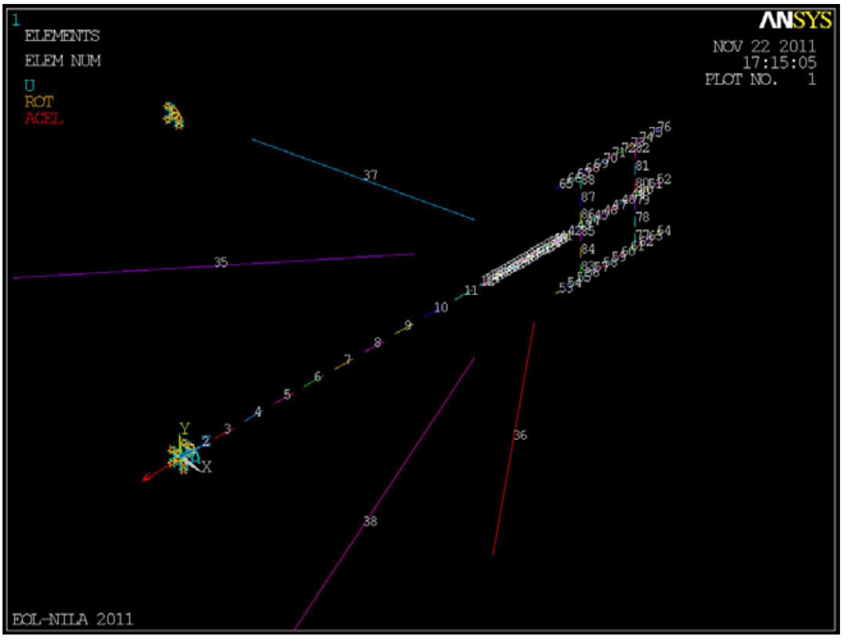

Fig. 6 The model for modal analysis

5. CONCLUSION

The project aim was to design a light weight, durable and economic wind turbine using commercially available parts and composite structural materials. Further to the design procedure outlined above there are still more design task required for a standard VAWT design project.

These include the refined design, prototype building, prototype testing, wind turbine design production.

This paper aims to ensure quality and safety for this kind of wind energy converter.

REFERENCES

[1] I. Nila et al., *Proiect turbina eoliana Darrieus 2011*, INCAS, 2011.

[2] Norsharizi Binti Mohammad Bhkari, *Modal analysis of concrete bridge decks subjected to free vibration*, Faculty of Civil Engineering, University Teknologi Malaysia, April, 2005.

[3] ***, ANSYS **12,** 2010

[4] M. A. Silva et al., *Formulations for the optimal design of RC wind turbine towers*, EngOpt, International Conference on Engineering Optimization, Rio de Janeiro, Brazil, 01-05 June, 2008.

[5] Y. V. Makarov, Z.Y. Dong, *Eigenvalues and Eigenfunctions*, Center for Energy Systems And Control Department of Electrical Engineering Howard University, Washington D.C.

[6] M. M. Rahman et. al, Finite element based vibration fatigue analysis of a new two-stroke linear generator engine component, *Int. J. of Mechanical and Materials Engineering*, vol **2,** no.1, .63-74, 2007.

[7] R. J. Allemang, D. L. Brown, *Experimental modal analysis, Harris' Shock and Vibration Handbook*, McGraw –Hill, 2009.

[8] K. Meerbergen, Z. Bai, The Lanczos method for parameterized symmetric linear systems with multiple right-hand sides, *SIAMM J. Matrix Anal. Appl.*, vol **31**, no.4, pp. 1642 - 1662, 2010.

[9]. J. Hunter et al., *Project #625 Wind turbine project, Final Report*, 31st October, 2008.

[10] M. C. Claessens, *The Design and Testing of Airfoils for Application in Small Vertical Axis Wind Turbines*, TU Delft, Nov. 9, 2006.

[11] *** , *IEC 61400-1 Wind Turbines, Part 1-Design Requirements*, Geneva, 2000.

[12] C. Bekas, Y. Saad, *Computation of smallest eigenvalues using spectral Schur Complements*, University of Minnesota, grant NSF/ITR-0082094

[13] B. N. Maker, D. J. Benson, *Modal methods for transient dynamic analysis in LS-DYNA*, 7th International LS-DYNA Users Conference

[14] ***, Methodes d'analyse en dynamique utilisées dans le logiciel robot, *Robot Millenium*.

[15] J. DeCoste et al., *Self-starting Darrieus wind turbine*, Dalhousie University, April 8, 2004