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EXPERIMENTAL INVESTIGATION ON WIND TURBINES BLADES USING VIDEO IMAGE CORRELATION (VIC)

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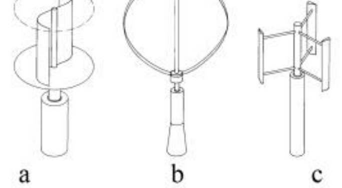
Abstract: *In this paper are studied the deformations of a vertical axis wind turbine blades, under the action of centrifugal forces. First is made a presentation of the different types of wind turbines, then it is passed to describing the problems encountered, and the solutions, in order to improve the design and the performance of a Darrieus wind turbine. Next is described the testing stand, the methodology and the results of the experimental tersting. The results are also compared with numerical simulation. It is concluded that the experimental set-up is proven to be adequate, precise and very versatile.*
Keywords: *Video Image Correlation (VIC), vertical axis wind turbines (VAWT), scale model, testing stand, deformations*

1. INTRODUCTION. MAIN ASPECTS REGARDING VERTICAL AXIS WIND TURBINES

The wind turbines are systems that are transforming the kinetic energy from wind in mechanical energy – through the blades. The mechanical energy is then transformed in electrical energy by means of an electric generator.
The wind turbines can be divided into two main categories according to the axis orientation: vertical axis (VAWT) and horizontal axis (HAWT). The most popular ones are the horizontal axis. This design is more appropriate for open areas with more constant wind direction and behavior. When we talk about urban environment, the wind turbines need a different positioning, and the rotor design should be made carefully. Among the small power wind turbines, implementable in urban environment, the vertical axis ones are proving to be more appropriate due to their ability to capture the wind from any direction, to work in turbulent wind conditions, and to facilitate the access to the control system.
There are two main types of VAWTs, according to the functioning principle: Savonius and Darrieus.
The Savoius is a drag type machine, where the wind is "pushing" the blades, which leads to limitations in rotational speed of the turbine, and thus in the power it produces. Between the cup-shaped blades there is a small gap which brings a small component of lift. The classical configuration is with two semi-cylinder blades and two circular plates at the ends. The blades can be positioned with different overlapping ratios. The most common example of this solution is the anemometer. These turbines have been thoroughly studied and we can find in literature several studies that are aiming to improve the power coefficient, and hence a better performance. Thus, the best result has been given by the 2 and 3 bladed solutions. The best power coefficient has been given by the 2 bladed rotor: 0.25, and the 3 bladed one gives only 0.16. Results that this design can convert in mechanical power – at the rotor level - maximum 11% of the undisturbed air flow.
The Darrieus design is a lift-type device. The blades have an aerodynamic profile which gives the possibility to reach rotational velocities higher than the wind speed. In [1] Mertens shows that, for a lift-type rotor, the maximum power coefficient is $C_{P,max} \approx 0.59$.



a b c

Figure 1: The two VAWT types: a. Savonius, b,c. Darrieus [2]

From the two VAWT types, the Savonius has the advantage of easily self-starting at low wind speeds, but provides low power coefficient. On the other hand, Darrieus has self-starting problems but reaches higher power coefficient. Thus, it is preferably to use Darrieus wind turbines and find solutions for improving the self starting capacity.

2. REQUIREMENTS IMPOSED FOR DARRIEUS TURBINE BLADES

Based on the state of art thorough analysis for the Darrieus VAWT type blades have been formulated the following basic requirements:

- To have optimized aerodynamic profile, in order to convert as efficiently as possible the wind energy in electrical energy
- To be as light as possible, in order to start easily in low wind speeds and have higher efficiency due to lower inertia.
- To be flexible, such as to adapt as good as possible to the environment conditions (i.e. to a wind with a certain intensity and frequency)
- Do not have natural frequencies in the functioning domain, conditioned also by the wind and the pole.
- To have higher fatigue resistance, because during functioning the blades are subjected to periodical loadings; let us just think about the effect of centrifugal force in deformations and stress.

In this regard, from the last requirement point of view could be mentioned the fact that, together with rotational speed change, takes place also a change in relative position of the blade ends, which leads to a bending of a different intensity.

Obviously it should be taken into consideration also the effect of centrifugal forces and aerodynamic forces, as the blades are subjected to extremely complex compound stresses, which are significantly varying with the change in working regime.

Considering even only these minimal requirements, the authors have investigated in this first stage, the degree of 3D deformation of the blades with the rotational speed. Based on the results, have decided to formulate more strict criteria regarding the choice of blades material (which usually is a composite one).

3. ORIGINAL TESTIG STAND

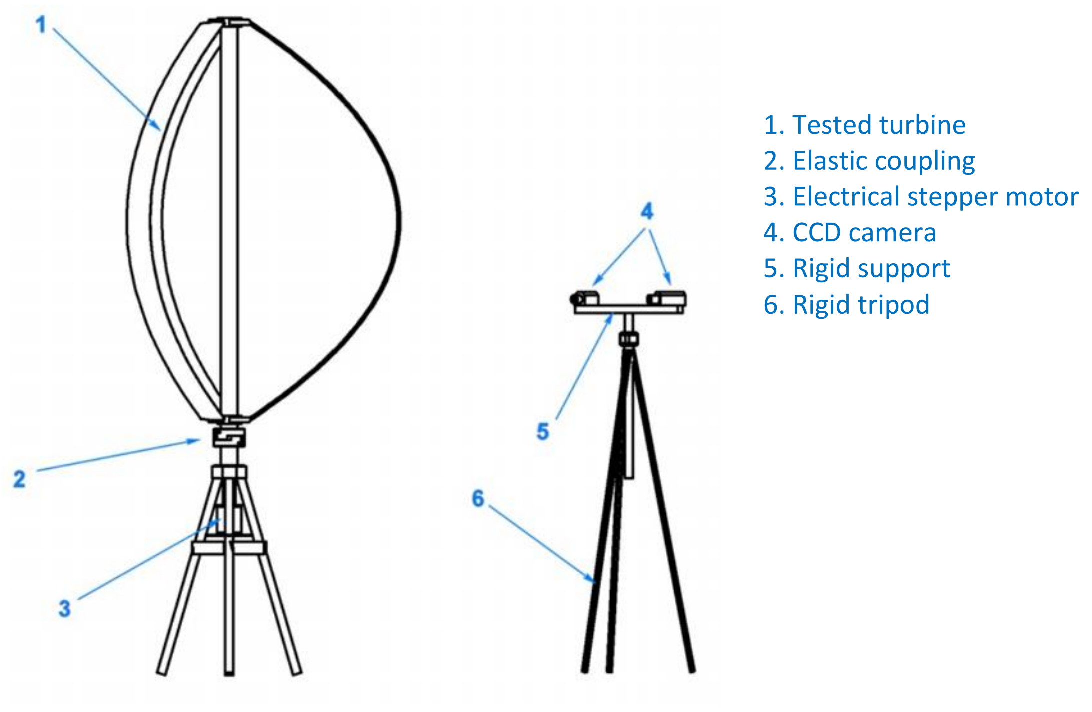


Figure 2. Testing stand for monitoring the centrifugal forces effect by rotating the turbine shaft

3. VIC METHOD

In order to perform a high-accuracy 3D evaluation of the displacement field, during the rotation of the blades, the authors have chosen the Video Image Correlation (VIC) method.
Its strobo-module (the *3D-Vibro-correlation module*) assures these requirements.
The VIC method is a full-field contact-less method and its 3D version practically eliminates all disadvantages or limitations of most used experimental methods.
Mainly, the system consists of two high-resolution video cameras, mounted on a tripod by means of a high-precision connecting rod (see Figure 3).

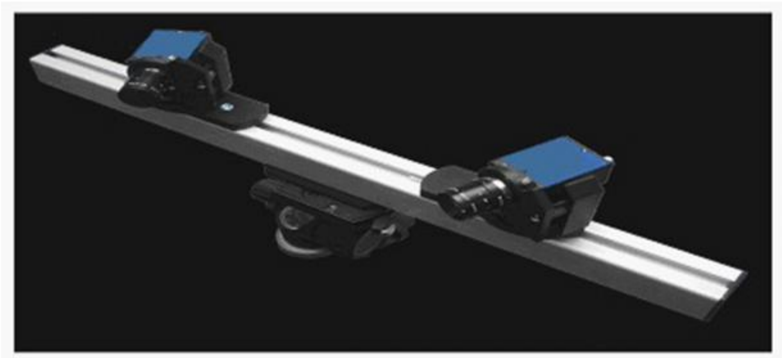


Figure 3. The VIC-3D setup [3, 4]

One can be applied in normal working conditions (not only in laboratories), because its software allows *eliminating the rigid body movements from the displacements field*, which represents one of its main advantages!
In advance, the tested object is sprayed with a water-soluble paint, in order to obtain a non-uniform dotted surface; the sizes of dotes depend on the surface sizes. In this way one can assure different grey-intensity of each pixel from the analyzed surface.
Before beginning of the tests, one has to perform a calibration, using some special targets/plates provided with a number of some high-accuracy set of dots (Figures 4 and 5), disposed adequately (in the plane corresponding to the predictable median plane of the tested object's surface). The target is rotated in horizontal and vertical plane in order to allow to the program a high-accuracy recognizing the 3D displacements of the significant pixels of the captured images (see explanations at Figure 6).
After the calibration, the cameras will perform the image acquisition in an [$n*m$] matrix of pixels, firstly for the unloaded tested specimen (where one has to define *the area of interest*) and after then: for the loaded one.

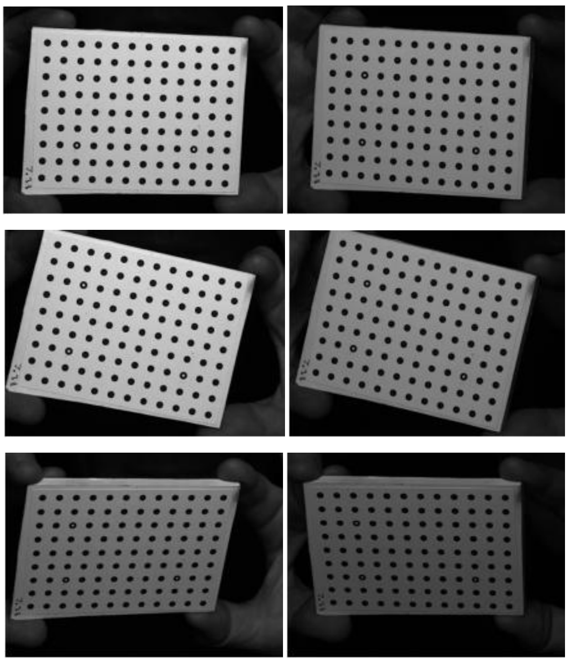


Figure 4. Different stages of the calibration process of each camera [6]

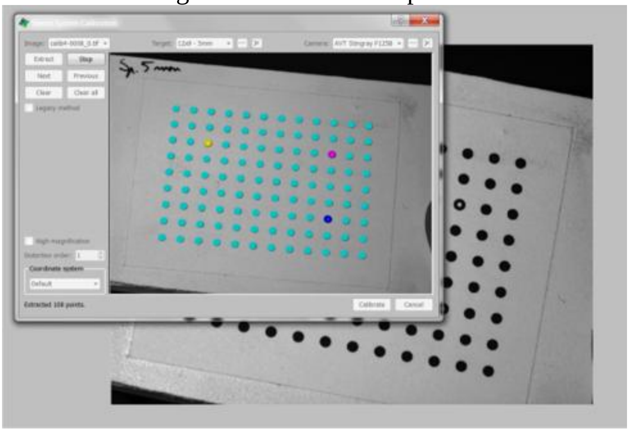


Figure 5. The extracting of the calibration points for the stereo calibration [6, 5]

Each captured image (by these two cameras), corresponding to the initial state of the object (more exactly: only the predefined area of interest), will be analyzed step-by-step (based on the principle schema from Figure 4).
So, the program allows the pre-selecting of a *Subset* (primarily cell) sizes (here: 5.5=25 *pixels*), respectively the step-magnitude (step size) for moving/translating of the Subset in horizontal and vertical plane).
For this Subset the program will establish /determine a unique grey-code, correlated to its median pixel high-accuracy 3D positioning.

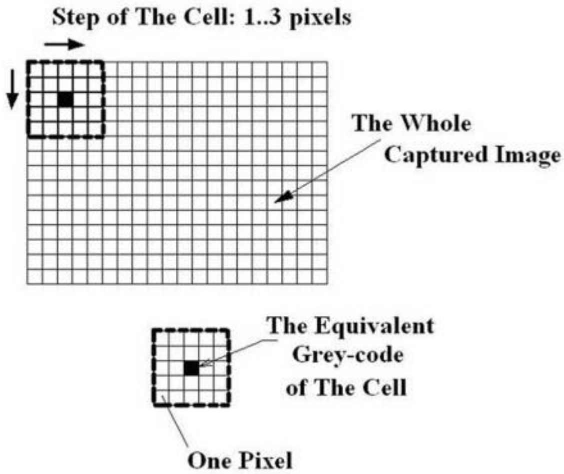


Figure 6. The measuring principle based on the scanning procedure [4, 5]

By analyzing of the whole image (by crossing over it with a pre-selected step: a number of pixels), each Subset cells will obtain a nominated (unique) high-accuracy spatial positioning and also a unique grey-code, too.

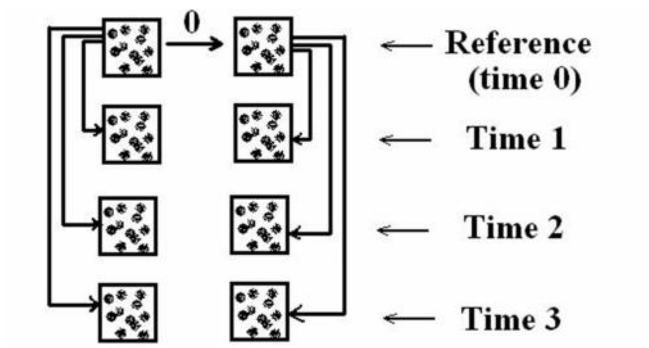


Figure 7. The stereo images analysis [4, 6]

After loading of the tested specimen, for all captured images (only in the area of interest, of course!), the program will identify the new positions of these Subsets, by performing an adequate comparison: *only once are compared the left and right images* (at time 0), after then, the succeeding left images are compared to the left reference, and succeeding right images are compared to the right reference (see Figure 7).
In order to perform an adequate evaluation/analysis of the captured images, the software requests, on the reference states, one single point's (meaning: one Subset's) identification on the left and right captured images; based on this single identification, the software will perform the identification of all Subsets in all captured images-pairs.
The same procedure will be applied in the strobo-mode, too, where the first image-pair will be captured in the static state of the object.
After that, by means of the stroboscopic image capturing, the 3D displacement capturing and analysis will be performed similarly.

5. A FEW PRELIMINARY RESULTS

Based on the previously described VIC methodology, have been prepared the blades. The monitoring system software allows the capturing of the images with the rotational speed of the blades. Hence, we will have the possibility to follow the 3D deformations field (and to save the data) at the level of a blade.
Also, the software allows the immediate establishment of specific linear and angular deformations for the same field of vision. These obtained data through experiment will serve as validation parameters for the numerical modeling.
In this case, the illustration of VIC method efficiency has been made by monitoring the deformations of the blades due to centrifugal forces at angular constant speeds (respectively at the corresponding frequencies of 1.0559, 1.47, 1.6447, 1.84, 2.0357 Hz).
A numerical analysis in Ansys has been performed together with the monitoring of scaled model deformations. The comparative results have been illustrated at the level of point with coordinates: R=333mm, H=397mm, with the coordinate system origin placed at the upper end of the blade.
For the numerical analysis have been introduced as input data the mechanical characteristics of the composite material from which has been made the scaled model.
As a result of the forced rotation of the turbine, the effect of centrifugal forces will lead, to the deformation of the blades.
In this simplified version of the stand (when there are not considered the aerodynamic forces by a wind tunnel), it is possible only the deformations evaluation of the blades.
In case is needed the experimental evaluation of the oscillating moment effect on the system, then we eliminate the elastic coupling from the system.

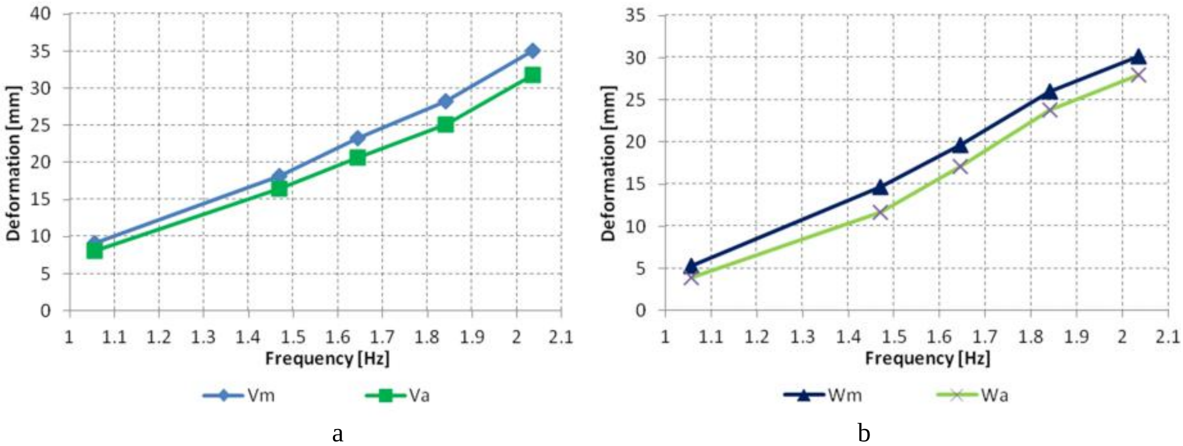


Figure 8. a. Variation of the point deformation on axial direction: Vm – experimental values, Va – numerical calculus values; b. Variation of the point deformation on radial direction: Wm – experimental values, Wa – numerical calculus values

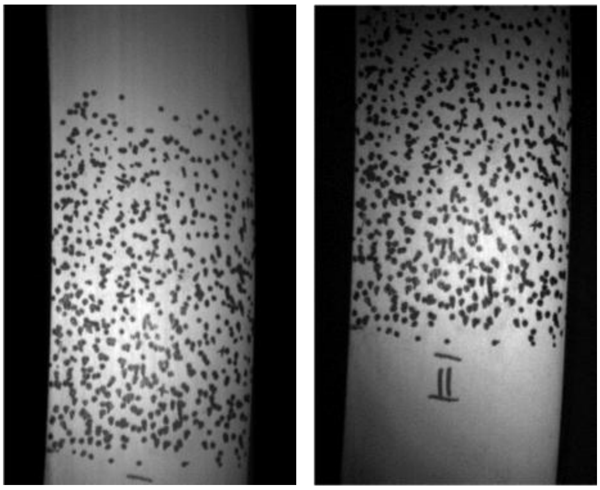


Figure 10. Blades deformations recorded by a camera: initial position and at maximum rotational velocity

3. CONCLUSIONS AND PERSPECTIVES

The original method presented, and illustrated by measurements, is, in authors' opinion of a great efficiency. Also, as we know, this methodology has not been previously used in analysis of wind turbines, so, it is a premiere.

The previously described methodology it maintains its remarkable qualities not only when applied to scaled models but also when it is desired to investigate the behavior during functioning for a real wind turbine scale model. Also, the method can be used in case of wind tunnel testing, for scaled models.

Must be acknowledged the special qualities of the VIC system, by its capacity to monitor the total deformation field (3D), as well as the wide range of the deformations (from a few microns to a few cm or more).

The authors are hoping that, based on these preliminary results, there will be a national and international collaboration with companies or universities.

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