1. INTRODUCTION

The implementation of Renewable Energy sources close to the place where are used as energy suppliers, have lead to new research directions. One of these is the implementation of small power, vertical axis wind turbines (VAWTs) into the urban environment.

Hence, a thorough study has to be made before designing and implementing a VAWT. Besides the aerodynamic improvements that can be brought to a wind turbine, a very important – and often disregarded – aspect is the influence of the rotating mechanism on the building structure. This means the study of the vibrations induced during rotation, at different wind speeds. Hence, the material from which are made of the blades can both influence the structural impact as well as the aerodynamic behaviour.

The influence of the blades geometry and material on the structural behaviour of the entire rotor can affect mainly two areas:

1. The aerodynamic behaviour of the blades: if the material the blades are made of is more elastic, then the rotor can obtain a higher freedom in obtaining the optimal blade shape during functioning.

2. The structural behaviour: induced vibrations to the building roof and upper elements.

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

- To be flexible, such as to adapt as well as possible to the environmental conditions (i.e. to a wind with a certain intensity and frequency). Here has to be taken into consideration that the urban environment is characterized by low wind speeds (3-6 m/s), high level of turbulences and gusty wind (sudden changes in wind direction and speed – which are determining high stress in the structure)

- To have an optimized aerodynamic profile, in order to convert the wind energy as efficiently as possible in electrical energy. Due to low wind speeds
there must be found a “compromise” between a high performance profile and a (usually cambered) profile that helps the turbine to start itself.

- Do not have natural frequencies in the functioning domain, conditioned also by the wind speed and the pole.
- To be as light as possible, in order to start easily at low wind speeds and have higher efficiency due to lower inertia.
- 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’s point of view the fact could be mentioned that, together with rotational speed change, also a change in relative position of the blade ends takes place, which leads to a bending of a different intensity.

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

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, we have decided to formulate more strict criteria regarding the choice of the blade’s material (which usually is a composite one).

The authors have refined their research in small power wind turbines, by performing experimental measurements on a scaled-rotor, considering the above mentioned requirements and problems.

2. TESTING METHODOLOGY

The testing methodology was carefully chosen so, regardless of the rotor dimensions, material and emplacement it was possible to determine the displacements in the structure at different rotational speeds.

Thus the chosen testing methodology is the Video Image Correlation technique.

**Video Image Correlation (VIC)**

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 the requirements mentioned before.
The VIC method is a full-field, contactless 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 1).

![Fig. 1](image)

The VIC-3D setup [3, 4]

One of its main advantages consists in the possibility of being applied in normal working conditions (not only in laboratories), because its software allows eliminating the rigid body movements from the displacements field.

The steps in the analysis have to be followed in a certain order:

1. The tested object is sprayed with a water-soluble paint, in order to obtain a non-uniform dotted surface; the sizes of dots depend on the surface sizes. In this way one can assure different grey-intensity of each pixel from the analyzed surface.

2. 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 2 and 3), disposed adequately (in the plane corresponding to the predictable median plane of the tested object surface). The target is rotated in horizontal and vertical plane in order to allow to the program high-accuracy recognition of the 3D displacements of the significant pixels of the captured images (see explanations at Figure 4).

After the calibration, the cameras will perform the image acquisition in a \([n*m]\) matrix of pixels, firstly for the unloaded tested specimen (where one has to define the area of interest) and then, for the loaded one. For each measurement another set of images is captured.
Fig. 2

Different stages of the calibration process of each camera [6] and extracting the calibration points for the stereo calibration [5; 6]

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.

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 a unique grey-code, correlated to its medium pixel high-accuracy 3D positioning. 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.

After loading of the tested specimen, for all captured images of the area of interest, the program will identify the new positions of these subsets, by performing an adequate comparison: the left and right images are compared only once (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.

In order to perform an adequate evaluation of the captured images, the software requests, on the reference states, one single point’s (meaning: one subset) 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.

![Testing stand for monitoring the centrifugal forces effect by rotating the turbine](image)

**Fig. 3**

Testing stand for monitoring the centrifugal forces effect by rotating the turbine

### 3. RESULTS

The blades have been prepared based on the previously described VIC methodology. The software of the monitoring system 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. The data which were obtained through the experiment will serve as validation parameters for the numerical modelling.

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=333 mm, H=397 mm, with the coordinate system origin placed at the upper end of the blade.

For the numerical analysis the mechanical characteristics of the composite material from which has been made the scaled model (MAT GF rowing) have been introduced as input data. For simplicity it was considered as quasi-isotropic.
<table>
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<th>Property</th>
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<tbody>
<tr>
<td>Density</td>
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<td>Kg / m(^3)</td>
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*Isotropic material*

<table>
<thead>
<tr>
<th>Property</th>
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<td>Pa</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>2.9615E+09</td>
<td>Pa</td>
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</table>

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 the aerodynamic forces by a wind tunnel are not considered), only the evaluation of the blade’s deformations is possible.

In case the experimental evaluation of the oscillating moment effect on the system is needed, we eliminate the elastic coupling from the system.

![Fig. 3.](image)

a. Variation of the point deformation on axial direction: \( V_m \) – experimental values, \( V_a \) – numerical calculus values; b. Variation of the point deformation on radial direction: \( W_m \) – experimental values, \( W_a \) – numerical calculus values

![Virtual representation of the FEM mesh on the rotor](image)
4. CONCLUSIONS

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

The special qualities of the VIC system have to be acknowledged: 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 multiple companies and universities.
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REFERENCES