GEODESIC TECHNIQUES USED TO MONITORING THE WIND TURBINES TOWERS

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***Abstract**: Development of renewable energy domain, and in particular of wind energy, required adapting known geodesic methods for monitoring the towers on which are located the wind turbines. Accuracies of determining displacements and deformations for this type of construction are usually high. To achieve these goals are presented and customized the geodetic methods used for determining the deviations from verticality and methods for determining the settlements.*

***Keywords:** wind turbines, geodesic methods, verticality, foundation settling*

1. Introduction

Wind turbines can be categorized into three classes: small, medium and large. Small wind turbines are capable of generating 50-60 kW power and use rotors with a diameter between 1-15 m. Most of the devices are wind turbines of medium size, they use rotors that have diameters of 15-60 m and a capacity between 50-1500 KW. Large wind turbines produce up to 1.8 MW and have a propeller blade over 40 m, being placed on towers over 80 m.

In Romania, with the exception of mountain areas, where weather conditions make installation and maintenance of wind generators difficult, speeds at or above the level of 4 m/s are found in the Central Moldavian Plateau and in Dobrogea. The seaside presents also potential energy, as in this part of the country annual average wind speed exceeds the threshold of 4 m/s.

2. Precision requirements on the monitoring of wind turbines

Given the impressive size of the rotors and the heights of the towers that exceed 100 m, the stability supervision of these structures is very important.

Beside physical methods of performance monitoring that allow determination of the relative deviations, geodetic methods are very important because they allow absolute determination of deviations for the structure [1, 2].

Deviations monitoring using geodetic methods can be approached from the point of view of determining deviations from verticality and in terms of studying settlements [4].

Monitoring deviation from verticality

Monitoring deviations from verticality of the tower involves making determinations for three different positions of the turbine nacelle. The accuracy of the determination should not exceed 1 cm. Determination technique for achieving such accuracy requires [7]:

- Making measurements of horizontal directions tangent to the circumference of the tower, at different levels of the tower, from three reference points located symmetrically to the center of the tower, situated at distances which will allow making measurements in good condition.
- The reference points will be integrated into a local linear-angular network, enabling the determination of the planimetric position of these points.

Determination of deviations from verticality can be approached in two ways:

- Through determination of the coordinates for the tower center at each level, determined by intersecting horizontal directions toward the center of the tower and then the deviations for each observed level.
- Through the determination of the directions toward the center of the tower as the average of horizontal directions tangent to the tower and then of the transverse deviations on each direction through composition of the resulting vectors, determining the deviation at each level of the tower.

<u>Determination of Settlements</u>

For the determination of settlements will be used the method of geometric precision levelling [3]. The accuracy of the determination should not exceed 1 mm.

The technique of determining includes:

- The placement, with geotechnical notice of at least three reference benchmarks, enabling the control of their stability and the correct determination of settlements.
- Making the geometric precision leveling measurements which includes the reference benchmarks and the settlement marks located in tower foundation of the wind power plant.

3. Case Study

Studied wind power plant (Fig. 1.) is located near the village Casimcea in Constanta County, as part of a park composed of about 30 plants. The wind power plant tower is built from concrete segments up to the height of 83.3 m, and metallic sections up to a height of 106.9 m, having the base radius of 4.5 m.

Fig. 1. Monitored wind power plant

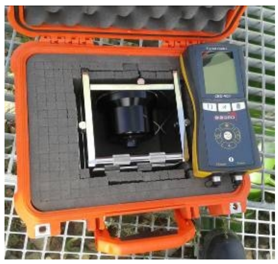

Fig. 2. Tiltmeter

For current monitoring are used determinations made with electronic tiltmeters (Fig. 2.) placed in positions and special places disposed radially inside the tower. Following these determinations were requested performing of monitoring observations through geodetic methods.

According to the monitoring requirements was taken into account making the measurements for three different positions of the nacelle, as can be seen in the following figure.

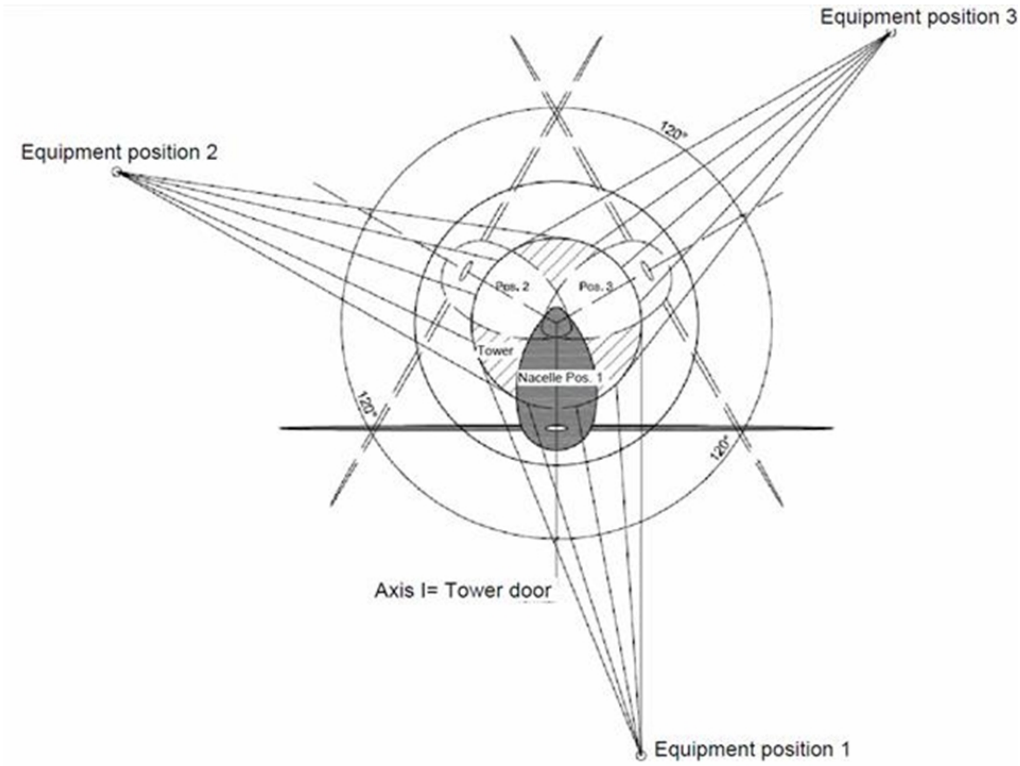

Fig. 3. Positioning of the nacelle in order to make the measurements

In order to make measurements regarding the deviation from verticality were materialized three points which form an equilateral triangle that has the center of gravity in the axis of the tower (Fig. 4.). The positioning of points was performed with centimeter accuracy using GNSS technology, the equipment used was the Topcon GR5 GNSS receivers connected to the national positioning sistem – ROMPOS [5, 10].

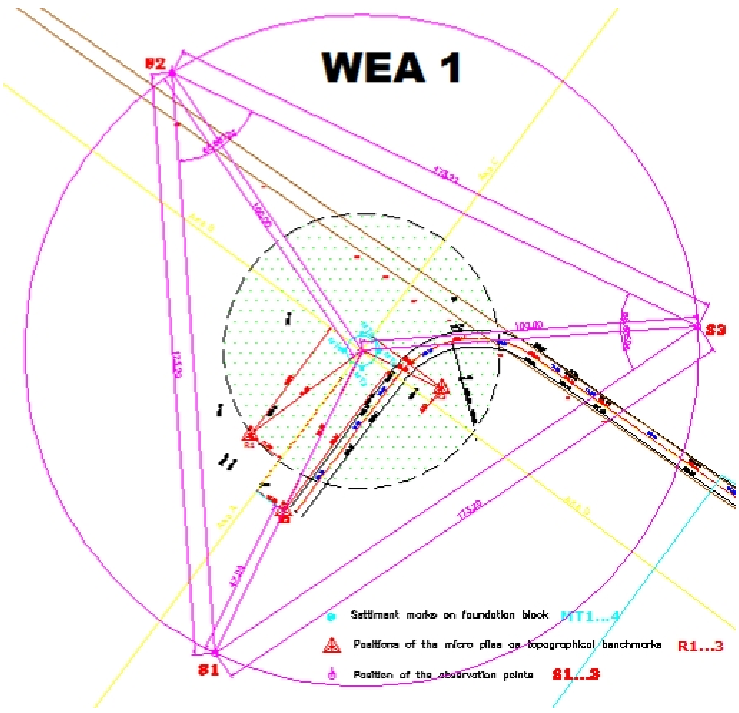

Fig. 4. Location of the points used to determine deviations from verticality

In the stakeout points S1, S2, S3, have been made high accuracy determinations using the Leica TC802 total station, which has the standard deviation for the determination of angles of 2" and for the distance of 2mm + 2ppm. In order not to induce errors due to the reduction to the Stereographic 1970 projection plane it was established that the determination of the coordinates of the points from which observations were made and of the center tower at each level to be calculated in a local coordinate system.

From every point observations were made in both positions of the telescope, at different levels specified by the beneficiary, for inclined visas being used a diagonal eyepiece.

Levels to which the measurements were made can be seen in the following sketch.

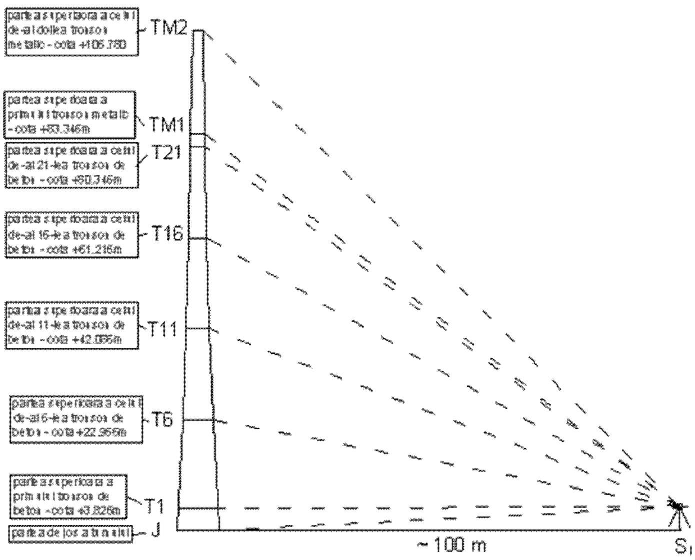

Fig. 5. Measurement sketch

Aspects from the measurements can be seen in the following images.

Fig. 6. Aspects from the measurements

For each position of the nacelle measurements were performed from three points.

The following table presents the observations made in one of the station points: horizontal directions measured in both positions (Hz P1 and Hz P2, values in centesimal degrees), average value of direction (Hz M in centesimal degrees), horizontal distances (D), horizontal angle between the sides of orientation (U.O. in centesimal degrees), angular deviation at the level targeted relative to the base of of the tower (α in centesimal degrees), the tangent of the angle α and the linear deviation corresponding to angle α, perpendicular to the direction of sight (q).

Table 1. Measurements for determining the deviation from verticality

Nacelle Pos.1		Hz P1	Hz P2	Hz M	D (m)	U.O.	α	tan α	q (m)
S3	S2	263.8387	63.8371	263.8379	173.087	66.6754			
	S1	197.1630	397.162	197.1625	173.138				
	J	230.6087	30.6103	230.6095					
	T1	230.6096	30.6112	230.6104			0.0009	0.000015	0.001
	T6	230.6048	30.6073	230.6060			-0.0034	-0.000054	-0.005
	T11	230.6056	30.6095	230.6075			-0.0019	-0.000030	-0.003
	T16	230.5997	30.6019	230.6008			-0.0087	-0.000136	-0.014
	T21	230.5863	30.5916	230.5889			-0.0205	-0.000322	-0.032
	TM1	230.5884	30.5904	230.5894			-0.0201	-0.000315	-0.031
	TM2	230.5762	30.5785	230.5773			-0.0322	-0.000505	-0.050

Using the measurements, were determined the coordinates in the local system for the points from which the observations were performed and of the center tower at the concerned heights. Measurements were processed rigorously in each stage, obtaining the average standard deviation of the network composed of all points and individual standard deviations for each point [6]. The average standard deviation of the network was up to 5.3 mm, in the case of measurements made in second position of the nacelle.

In the table below were calculated the total deviations and the deviations relative to tower height in mm/m for each observed level, depending on the position of the nacelle.

Table 2. Total deviations and the deviations relative to tower height

Aimed level	Height of aimed level (m)	Nacelle Pos.1		Nacelle Pos.2		Nacelle Pos.3	
		Total deviation (mm)	Deviation (mm/m)	Total deviation (mm)	Deviation (mm/m)	Total deviation (mm)	Deviation (mm/m)
T1	+3.826	2	0.6	3	0.9	1	0.3
T6	+22.956	8	0.3	6	0.3	8	0.3
T11	+42.086	8	0.2	6	0.1	6	0.1
T16	+61.216	12	0.2	10	0.2	7	0.1
T21	+80.346	32	0.4	15	0.2	24	0.3
TM1	+83.346	29	0.3	18	0.2	27	0.3
TM2	+106.780	75	0.7	86	0.8	53	0.5

Graphical representation of these deviations can be seen in the following figure, where we see with blue (bottom) the deviations for position 1 of the nacelle, with red (to the left) the deviations for position 2 of the nacelle and with green (right) the deviations for position 3 of the nacelle.

To check the calculations were used the linear the deviations (q) determined from each measuring station through their composition was obtained graphically the value and direction of movement, the results are identical to those from rigorous processing of measurements.

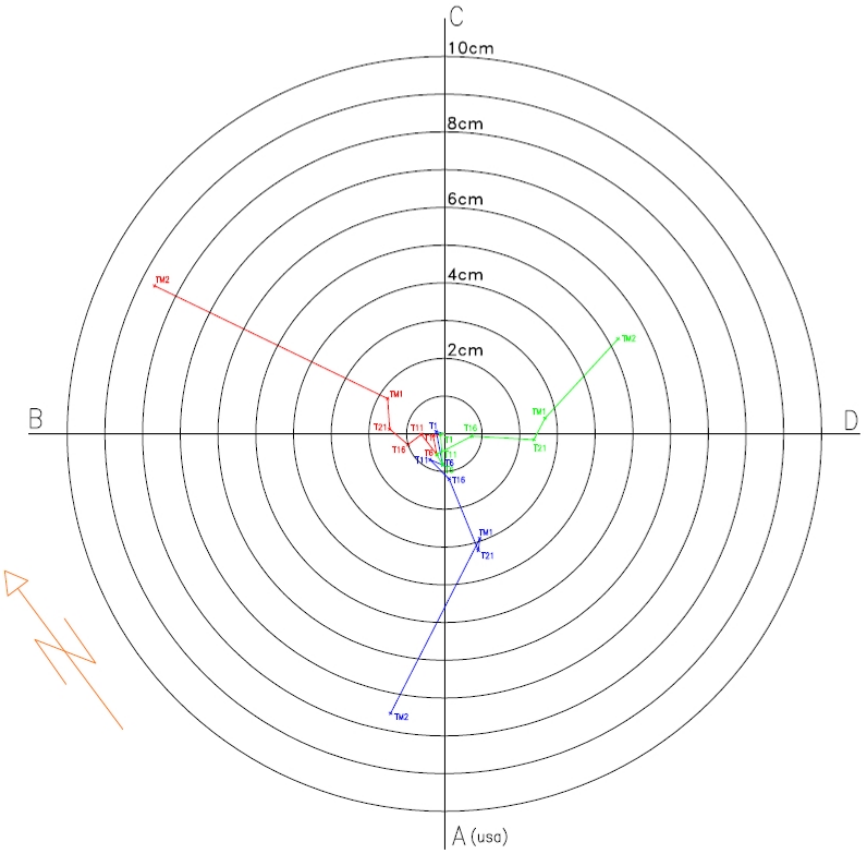

Fig. 7. Movements in the three positions of the the nacelle

For the determination of settlements has been used the digital instrument for geometric precision leveling Topcon DL-101C and the invar bar code staffs of 2m. This measurement system provides a standard deviation of ± 0.4 mm per km. double leveling. Also we worked to ensure the accuracy required (~ +/- 1mm), as provided by STAS 2745/1990.

During a stage of measurements were included the benchmarks R1, R2, R3 and the settlement marks M1, M2, M3, M4, which are placed as shown in figures below.

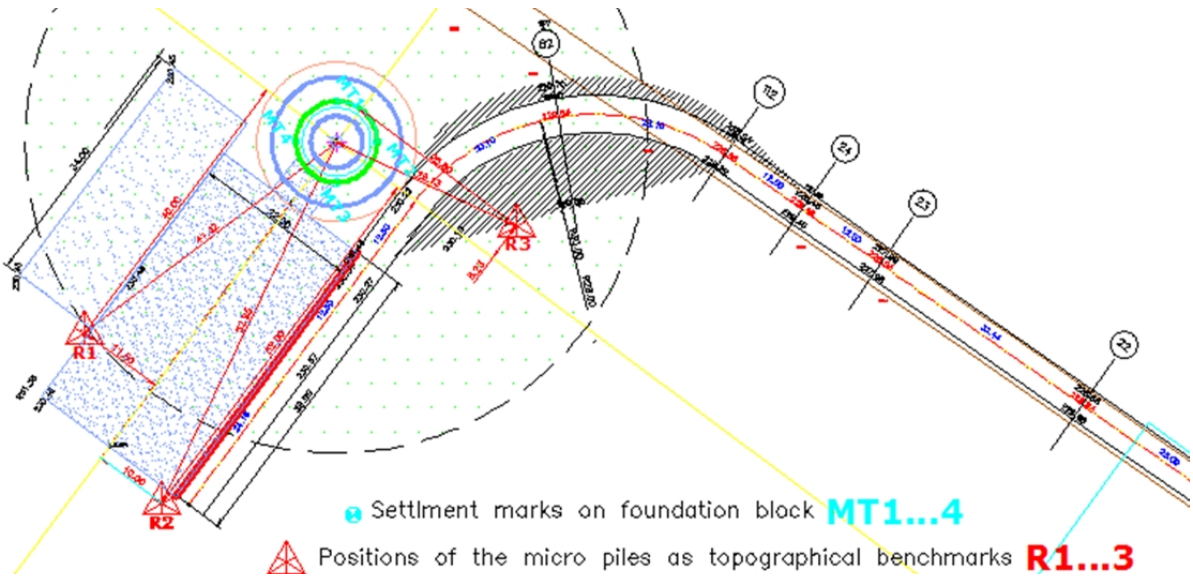

Fig. 8. Location of the benchmarks and the settlement marks

Fig. 9. Settlement mark, measurements, benchmark

Calculations were made as a closed traverse starting from point R1 (R1 is the altimetric reference benchmark), taking the benchmark height as 100.0000 m.

Misclosure of the level differences in these closed traverses are of tenths of millimeters, for which no compensation was necessary to make a correction calculation for the measured level differences.

The reference height values of benchmarks and settlement marks on the monitored target differ by no more than 0.4 mm, corresponding to the 3 positions of the wind turbine nacelle, these values falling within the accuracy requirements.

Table 3. Heights of the benchmarks and the settlement marks

Poin name	**Nacelle Pos.1 Height [m]**	**Nacelle Pos.2 Height [m]**	**Nacelle Pos.3 Height [m]**
R1	100.0000	100.0000	100.0000
R2	100.1295	100.1292	100.1295
R3	98.7843	98.7839	98.7842
M1	99.8866	99.8866	99.8865
M2	99.8821	99.8823	99.8822
M3	99.8918	99.8921	99.8919
M4	99.8794	99.8794	99.8795

4. Conclusions

Following the completion of measurements and performing their processing we can see that the use of geodetic methods for monitoring the wind power towers adds more information compared to performing monitoring using only physical methods. Precision requirements are ensured only if are used high precision instruments and adequate methods of measurement [8,9].

It is found that the nacelle position does not influence the foundation in terms of vertical movement and the svelte and flexible structure of the tower supports bendings in static regime of the rotor that can be cleared when operating under wind action because the rotor rotation speed can be controlled by adjusting the angle of incidence of the propeller blades.

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