STUDY OF THE ELASTIC STABILITY OF THE WIND TURBINE SUPPORT STRUCTURE BY USING NUMERICAL AND ANALYTICAL METHODS.

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Abstract - The paper is structured in five parts. In the first part is evoked the importance and presented some aspects from stability theory. In the second part are presented the general model designed by the author with the principal loads. In part three are presented the model for evaluation taking into account the forces given by the wind loads. In part four are given the results obtained using an analytical method neglecting the forces given by the wind loads. Are calculated the dimensions of the diameter and also is verified the section. In part number five the authors presents the conclusions .

Keywords: modelling, wind, turbine, stability, beam.

1. INTRODUCTION

As is known problems of stability theory is based on the assumption of small deformations, according to which the structural balance in the case of wind turbines is express on undeformed shape.

The loss of stability of the equilibrium shape of the model designed for post request will occur as a result of buckling. The problem of stability of different structures in this case for the wind turbine, present particular interest because, the initial equilibrium shape loss is accompanied by large displacements of points in section structures, which can lead to cracking and breaking it.

The analysis of the stability of the equilibrium forms of the wind micro-aggregate taken into consideration in this study is done by adopting a simple mechanical model designed in the following form:

- homogeneous column is considered made from OL37;
- wind turbine generator is considered to act statically on the support pillar, the mechanical model being in the form of a concentrated force acting at the free end of the structure. In this paper the authors consider the support pillar to be a vertically positioned beam. Also, the authors consider the vertical structure who supporting the wind turbine as a beam having one edge clamped and the other free.

In reality, the static action of this force is eccentric to the axis of the supporting pole, but the simplifying assumption is that the force of the generator acts in the mass center of the cross section at the free end of the clamped beam.

In order to make calculations more efficient, the hypothesis of homogeneity and isotropy of materials from which turbines and blades are made is also admitted. This hypothesis does not significantly affect the accuracy of the obtained results. Consequently, they will apply the boundary conditions for the clamped bars at one end and loaded with own weight force and wind action.

2. THE STATIC LOADING MODEL OF THE BEAM WITH VARIABLE SECTIONS.

When calculating the stability of the wind turbine, it is looking for dimensioning it taking into account the following external forces:

- the weight of the beam;

The weight of the pole is considered to be a uniformly distributed force, with constant intensity along its axis.

- weight of the wind turbine generator and blades;
- Wind load that will be considered as a linear load distributed with minimum ground intensity and maximum rotor height
- the external reaction forces horizontal and vertical in the section of the pole at the ground level.

The bending moment will also act as a bending moment that opposes the moment of overturning beam.

Given the type of forces and their mode of action on the wind turbine, is adopted the following simplifying hypothesis: the shape of the wind turbine blades is considered to be rectangular and their negligible weight at the entire structure.

3. INITIAL DATA ON THE AGGREGATED GEOMETRY AND THE WIND ACTIONS FORCES

The blade geometry considered for the wind turbine is the following:

- blade length L = 1.5 [m];
- flame width l = 0.20 [m];
- blade thickness g = 0.03 [m]

The mass of the turbine (the assembled blade generator) is considered to be:

$$m_T = 60[kg]$$

The dimensions of the turbine considered in the calculation of the considered model are:

- the length of the turbine $L_t \cong 0{,}70[m]$;
- Turbine width $l_t \cong 0{,}40[m]$;
- the height of the turbine $h_t \cong 0{,}50[m]$.

The height of the turbine support beam clamped at one end is:

$$h_B = 6{,}0[m].$$

The average wind speed for the geographic region considered is:

$$v = 10{,}0\left[\frac{m}{s}\right].$$

The unit loads from the wind action on the clamped beam are determined with the relation:

$$q_W = c_{TS} \cdot \beta_S \cdot p,$$

where:

$c_{TS} = 0{,}7$ the aerodynamic coefficient determined for metal beam with the circular section;

$\beta_S = 1{,}63$, represent the coefficient of flurry on the beam height, which depends on the wind turbulence and the dynamic response of the structure. This includes the effect of wind variation with the height.

Loads generated by wind action are determined by the dynamic dynamical pressure using the relationship:

$$p = \frac{v^2}{16{,}3}$$

Considering the fact that the wind load is distributed as linear intensity at ground level will be considered as the minimum:

$$q_{WG} = 0\left[\frac{daN}{m}\right].$$

The direction of wind action on the wind turbine blades is considered to be perpendicular to them.

It is obtained for the intensity of the linear load distributed from the wind a maximum intensity at the free end of the wind turbine:

$$q_W = c_{TS} \cdot \beta_S \cdot p = c_{TS} \cdot \beta_S \cdot \frac{v^2}{16{,}3} \cong 7{,}0\left[\frac{daN}{m}\right]$$

4. STATIC BUCKLING CALCULATION OF THE WIND TURBINE TAKING INTO ACCOUNT THE WIND LOAD.

The value of the critical load at which appear the bifurcation (loss of stability) is:

$$P_{CR} = 220{,}455[KN]$$

For the static study, is used the numerical method - the finite element method. The structure represented by the symmetry axis of the bar and loaded with forces determined by the actual weight of the bar and the weight of the turbine is represented by the axis of symmetry of the shaft and discretized by 33 equidistant nodes [1], [2]. It determines the first three mode shapes of the loss of stability beam.

Using FEM, it determine the maximum displacement values for the first three forms of loss of structural stability.. The displacements magnitude and deformed forms are expressed in meters [m], and it was determinated using LISA FEM software.

The deformed shape of the structure for the mode 1 is presented in figure 1

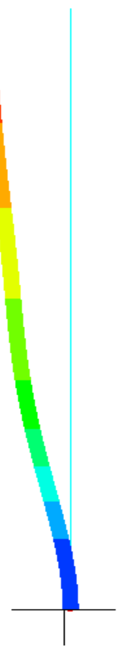

Fig. 1 - The shape deformation for mode 1

For the mode number 1 of buckling the displacements magnitude expressed in meters are:

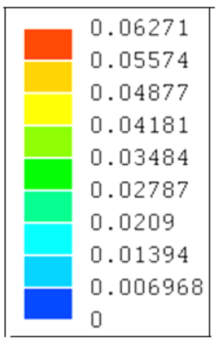

Fig. 2 - Displacement magnitude for mode number 1 expressed in meters

Fig. 3 - The shape deformation for mode 2

For the mode number 2 of buckling the displacements magnitude expressed in meters are:

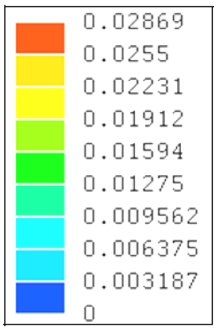

Fig. 4 - Displacement magnitude [m] for mode number 2 expressed in meters.

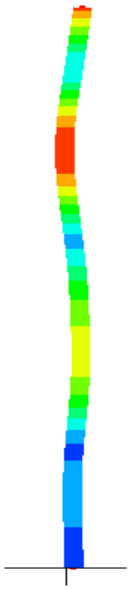

Fig. 5 - The shape deformation for mode 3

For the mode number 3 of buckling the displacements magnitude expressed in meters are:

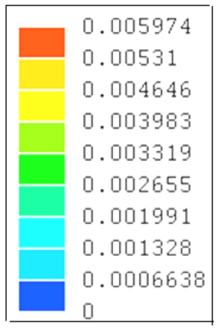

Fig. 6 - Displacement magnitude [m] for mode number 3 expressed in meters.

5. STATIC CALCULATION OF THE WIND TURBINE USING ANALITYCAL METHODS NEGLECTING FORCES CAUSED BY WIND LOADS.

The material can be found in the area of elastic, plastic or centric compression [4], [7].

The area of material behavior is established using the relationship:

$$\sigma_{CR} = \frac{\pi^2 \cdot E}{\lambda}, \quad (1)$$

$$\lambda = \frac{L_{FB}}{i_{MIN}} \quad (2)$$

For:

$$\sigma_{CR} < \sigma_P$$

$$\downarrow$$

$$\lambda_0 = \sqrt{\frac{\pi^2 E}{\sigma_P}} \cong 104$$

$\lambda -$ slope coefficient;

$\sigma_P -$ proportional tension;

$i_{MIN} -$ radius of inertia

The buckling coefficient is selected from the tables [8], [9], [10]

$$\varphi = 0{,}555$$

It is determine the weight of the pillar turbine support. The stability calculation will necessarily take into account the weight of the steel beam, The relationship is:

$$G_B = q_B \cdot V_B = \rho_B \cdot V_B \cdot g$$

where:

$\rho_B = 7850\left[\frac{KN}{m^3}\right]$, represent, the specific weight of the steel from which the beam is made;

$A -$ the transversal area of cross section;

$V_B\left[m^3\right] -$ beam volume (the volume of the pillar);

$q_B\left[\frac{KN}{m}\right] -$ intensity of uniform distributed forces caused by the weight of the pillar;

The resultant force obtained is:

$$R = q_B \cdot h_S$$

$$R = 471 \cdot 10^3 [KN]$$

To avoid the loss of stability of the beam, the magnitude of the normal stresses produced by the axial force is limited by the stability condition [5], [6], [9]:

$$\sigma_{ef} = \frac{N}{A} \le \sigma_{CR} .$$

For determine the cross-sectional dimension, the axial momentum of the section is determined using the relationship [4], [5]

$$I_{\min} = \frac{R \cdot c_f \cdot L_{FS}}{\pi \cdot E} .$$

Where:

$c_{fi} = 1{,}6$, buckling safety factor;

$L_{FS} = 2h_S$, buckling length.

It is determined:

$$I_{\min} = 0{,}082[m^4]$$

Taking into account the moment of inertia from buckling we determine the area of the transversal section [5[], [9], [10]:

$$A = \frac{R}{\varphi \cdot \sigma_C} \tag{4}$$

$$A = \frac{R}{\varphi \cdot \sigma_C} = 0{,}0628\left[m^2\right]$$

,

Where:

$\sigma_C -$ normal compressive tension.

For the steel OL37,

$$\sigma_C = 1500\left[\frac{daN}{cm^2}\right]$$

$$D = \sqrt{\frac{4A}{\pi}} = 28{,}28[cm]$$

Checking of the section will be done by determining the safety coefficient [4], [7].

$$c_f = \frac{\pi^2 E I_{MIN}}{L_{FB} R} \tag{5}$$

Is calculated the radius of inertia using the relasionships [6], [8]:

$$i_{MIN} = \sqrt{\frac{I}{A}} \tag{6}$$

$$i_{MIN} = \sqrt{\frac{I}{A}} = 0{,}01[m]$$

The forces are maximum in the clamped section and the minimum on the free edge.

The proportional tension at OL 37 is

$$\sigma_P = 1900[daN/cm^2]$$

where:

$i -$ represent radius of inertia.

For the buckling coefficient the value is adopted from the tables containing the standardized values

$$\varphi = 0{,}166$$

The maximum value shall be taken into account in the static calculus [7], [8].

$$A_{NEC} \ge \frac{G_T + G_B}{\varphi \cdot \sigma_{adm} - \gamma \cdot h_B} = 201{,}9[cm^2]$$

$$D_{EF} = 16{,}037[cm]$$

So, it was adopted for the effective diameter significantly superior value, which checks the buckling calculation.

$$D_{EF} = 20[cm]$$

CONCLUSION

As the conclusions of this work the authors present these:

1. If we take into account the action of the wind loads and their own weights, the values of the maximum axial displacements of the structure were determined.

The values determined for the first three forms of loss and stability are:

A. Y = 0.062 [m] for its first form of loss of stability;

B. Y = 0.028 [m], for the second form;

C. Y = 0.005 [m] for the third form.

It is found that the maximum displacements are recorded for the first form of loss of stability, being about 55% higher than for the second form and about 92% higher than for the third form.

2. Since the values of wind load intensity are small and practically do not influence the stability of the wind turbine, in the second stage of the work, the calculation was performed statically using the analytical method for dimensioning and verification. They determined:

- coefficient of slenderness;
- buckling coefficient is obtained on the basis of the sink coefficient using the tables containing the standardized values;
- necessary diameter $D_{NEC} = 16{,}037[cm]$, value determined from the stability calculations;
- effective diameter $D_{EF} = 20[cm]$, value chosen by the authors, higher than the one determined by calculation;
- verification of transversal section is ensured because buckling safety factor is $c_{fi} < c_f$, so in this case it can be said that the structure material works on the elastic behavior domain.

The results determined by the authors in the paper can be considered as an analytical calculation model regarding the stability of vertical wind turbine supports.

REFERENCE

[1] Blumenfeld Gh. *Introducere in metoda* Bucuresti, 1995.

[2] Botis M. *Metoda Elementelor Finite.* Editura Universitatii Transilvania: 121-126. Brasov, 2005.

[3] Catarig A, Kopenetz L *Statica Constructiilor - Structuri Static Nedeterminate:* 56-78.Editura Matrix Rom, Bucuresti, 2001.

[4] Ciofoaia E, Curtu I, *Teoria elasticitatii corpurilor izotrope si anizotrope*. Reprografia Universitatii Transilvania Brasov, 1986.

[5] Fetea M. *Calcul analitic si numeric in rezistenta materialelor:*45-49. Editura Universitatii din Oradea, 2010.

[7] Gheorghiu H, Hadar A. *Analiza structurilor din materiale izotrope si anizotrope.* Editura Printech. Bucuresti, 1998.

[8] Goia I, Rezistenta Materialelor. Editura Transilvania Express Brasov, 2000.

[9] Ille V. *Rezistenta Materialelor II.* Atelierul de Multiplicare a Institutului Politehnic: 470-471. Cluj-Napoca, 1977.

[10] Ivan M. *Statica, stabilitatea si dinamica constructiilor. Teorie si Probleme*. EdituraTehnica. Bucuresti, 1997.