INFORMATION AND WEB TECHNOLOGIES

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AUTOMATED SYSTEM FOR MONITORING PARAMETERS OF TELE-RADIO MASTS / TOWERS AND ELIMINATION OF ABERRATION

Abstract. *The construction of Automated System for verticality and dynamic parameters monitoring of towers/masts is considered in that work. Modern technologies, such as MEMS sensors / inclinometers, Cloud Computing, SCADA, Mobile Internet are used in the System. Formulas for computing the tilt and vibration of towers/masts on the base of sensors / inclinometers codes and methods of spherical geometry are developed. Mathematical correlation between geodetically measurement data and sensors / inclinometers data are considered. The determining of initial setup for the sensors / inclinometers is solved on the base of geodetically measurement data.*

The graphical interfaces for monitoring process are developed. Practical implementation of the automated system for towers/masts verticality and dynamic parameters management as well as are developed.

Keywords: *SCADA, tower, mast, sensor, inclinometer, verticality, dynamic parameters.*

1. System architecture

Figure 1 shows the general scheme of the Automated Monitoring System for Deformation of Masts /Towers (AMSD).

The mast at the left is shown. Tilt-sensors / inclinometers are fixed at the fastening levels of braces of the mast. The tilt-sensors through thunder-protection modules are connected to a common cable and transmit information (data) through an RS-485 interface. Wind speed Sensor, Wind direction sensor and temperature-humidity sensors are also connected to the interface RS-485.

The lower end of the RS-485 cable is connected to the HOST-CONTROLLER, which manages and communicates with sensors. 3G modem implements data exchange with WEB-PORTAL SERVER via the mobile Internet.

WEB-PORTAL SERVER stores the sensors data received via the Internet from a 3G modem. Server application software processes the sensor data array and implements the user interface for displaying information. The user gets access to the Server via the Internet to the workstation (Figure 1).

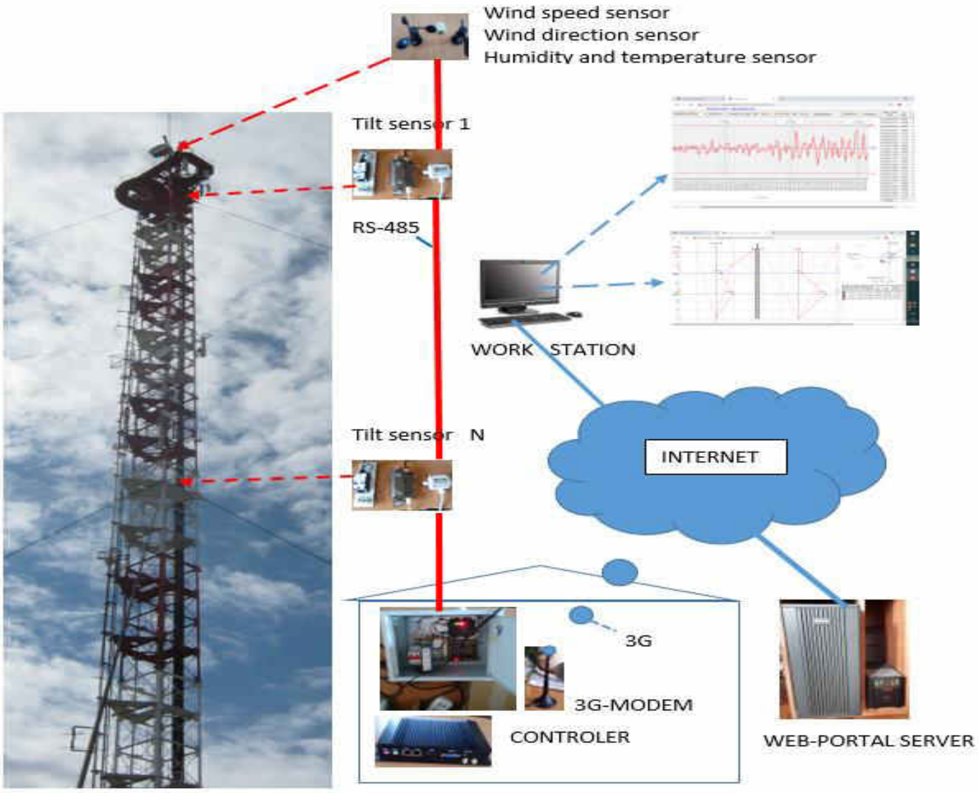


Figure 1. System architecture

2. Engineering measurements and calculations

There are many technologies and methods for measuring various parameters in the manufacture, construction and operation of high-rise structures, in particular masts and towers [1,2,3,4,5,6,7].

The main parameters to be measured during the operation of metal masts and towers are dynamic parameters and stability parameters.

2.1 Model

As an example, consider the measurement of the slope (verticality) of a mast with a 2-axis sensor-inclinometer (Figure 2).

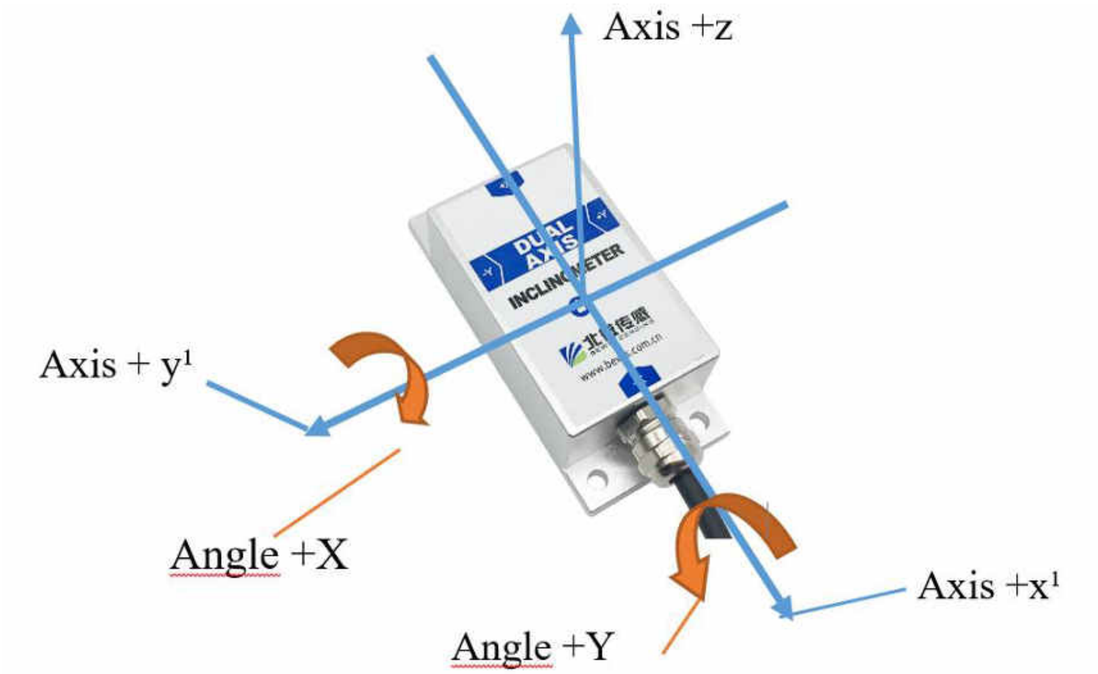


Figure 2. Biaxial tilt sensor

The arrows show the angles of rotation of the sensor (X, Y). The axes (x, y) represent a system of rectangular coordinates matched in directions with the angles of rotation and rigidly attached together with the sensor to the mast (Figure 3). Define the x, y, z coordinate system (Figure 3, Fig.4) as the base (normal) coordinate system of the mast-sensor, with x, y, z forming the right triple [8], where the x^1 axis is parallel to x and the y^1 axis is parallel to y but opposite in direction.

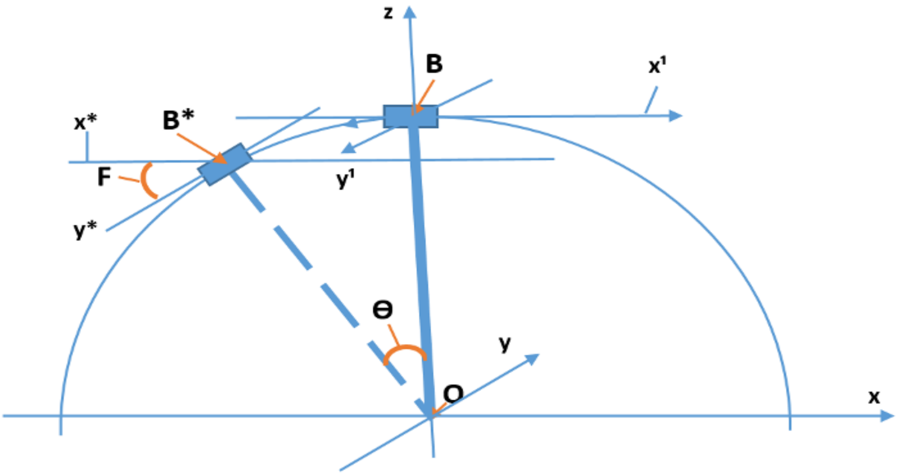


Figure 3. Rotation of sensor and mast

If you compare the coordinates of Figure 6 with the coordinates of Figure 4, then you can see that the coordinates of the sensor x^1, y^1, z forms the right three, if you change the sign of the y axis to inverse: $y^1 = -y$. This must be considered in further calculations.

Figure 3 shows the mast model when tilted in 2 positions: 1) upright-OB and inclined- OB*. The sensor is located perpendicular to the vertical axis of the mast. The angle F is the vector of the angle of the sensor, and the angle Θ is the vector of the angle of the mast. From Figure 3 it can be seen that the angle F is equal to the angle Θ, as are the angles with mutually perpendicular sides (OB is perpendicular to x*, and OB * is perpendicular to y *), i.e. the mast tilt vector is equal to the tilt vector of the sensor in the agreed coordinate systems of the sensor and the mast.

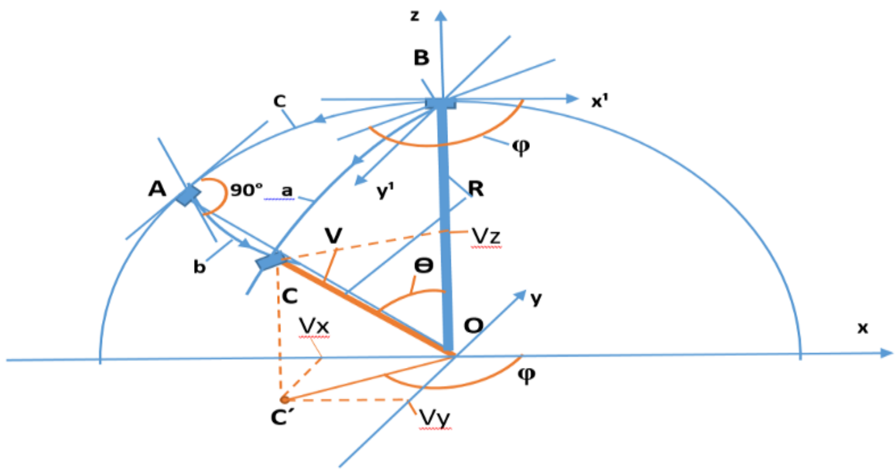


Figure 4. General case of mast tilt with sensor

The top of the mast B with a fixed sensor moves along a sphere with a radius equal to the height of the mast OB, when tilting the mast with a fixed base O. This position is valid for any intermediate point of sensor attachment on the OB axis.
Consider the general case of tilting the mast- sensor (Figure 4). Sensor movement from point B to point C can be represented as a vector sum of 2 movements: from point B to point A plus movement from point A to point C along a sphere with radius OA, where the spherical angle BAC is a rectangular [8].
Here A, B, C are spherical angles, and the letters a, b, c are opposite corresponding arcs [8].

According to the formulas of spherical trigonometry:

$$a = \arccos(\cos b \times \cos c) \tag{1}$$

$$B = \arctan(\tan b / \sin c). \tag{2}$$

a- amplitude of the deflection angle of the OB axis;
B-amplitude of the angle of deviation direction relative to the x, z.

In practice, at small deflection angles, as well as with a large radius R = OB (compared to an angle in radians), the triangle ABC can be considered planar and rectangular in the normal coordinate system x, y, z (or x^1, y^1, z), where angle A is rectangular, and tan b = b, sin c = c. Then formulas (5), (6) take the form:

$$a = \sqrt{(c^2 + b^2)} \tag{3}$$

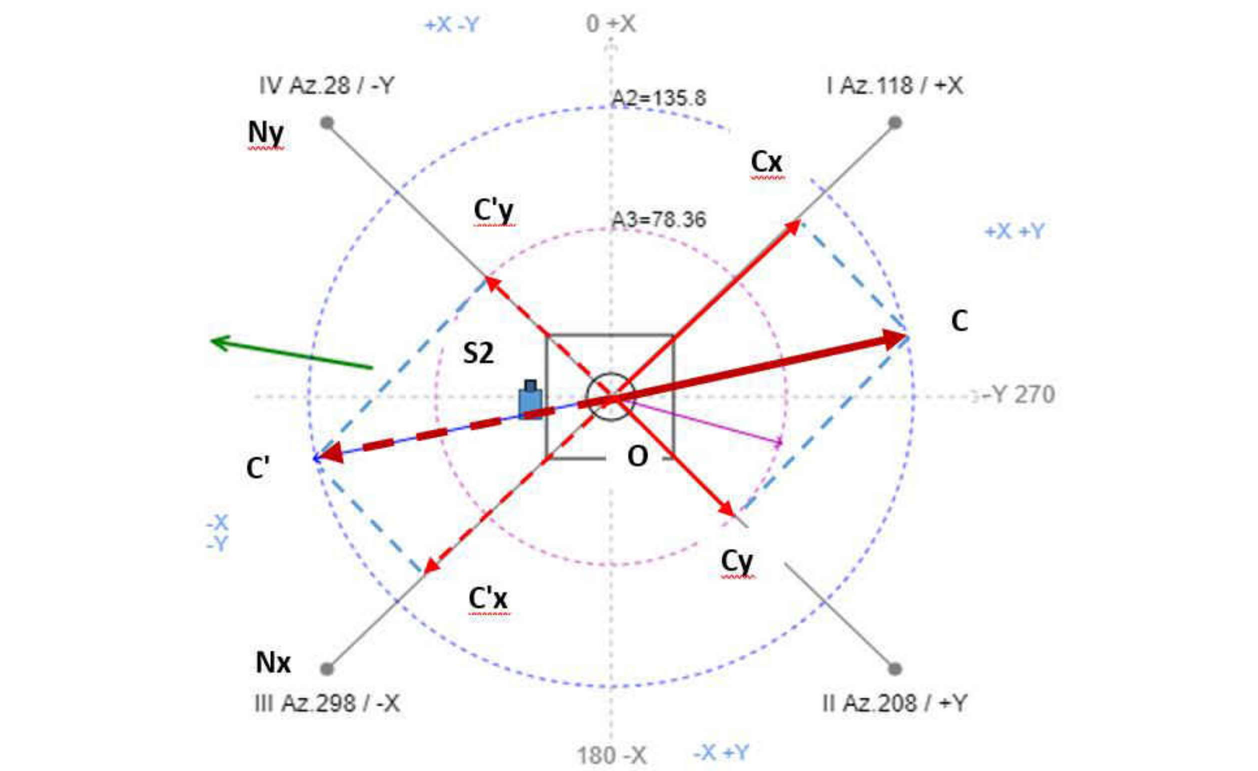
$$B = \arctan(b / c) \tag{4}$$

2.2. Complete corrections of the verticality and vibrations

Fig.3 shows a horizontal position (example) of the AMSD in the horizontal plane. The inclination of the mast is recorded by the sensor-inclinometer S2 with 2 mutually perpendicular axes (X and Y). O + X, O-X, O + Y, O-Y present the horizontal projects of the 4 lines at the level of the sensor. The table shows the numerical data, indicated by AMSD.

In order to neutralize the OC deviation, according to Hooke's law [10] we must apply a deviation equal to OC but in the opposite direction - OC' (fig.3). The designs of vector C on X and Y show OCx and OCy accordingly. The amplitudes OC, OCx, OCy are calculated by AMSD in table fig3 - “Ampl.”, “X”, “Y”, corresponding to:

C = 135.80 mm, Cx = 114.24 mm, Cy = 73.43 mm.



sens Nr.	sens H (m)	Norma mm	Norma° degr.	X° deg.	Y° degr.	Ampl° degr.	Ampl. mm	Y mm	X mm	artang (Y/X)	A∠±Y° degr.	Date/Time
2	49.85	33.23	0.038	0.1313	-0.0844	0.1561	135.8	73.43	114.24	-0.5713	57.3	14.03.2020 09:48:03:897
3	85.85	57.23	0.038	-0.0606	0.109	0.1247	78.36	68.49	38.08	-1.0634	29.1	14.03.2020 10:00:07:133

Figure 5. Example of the mast inclination (horizontal plan)

In FIG. 6 (vertical plane) a mast is shown in 2 positions: 1) O-O' until the verticality correction, 2) O-O” after the verticality correction; D-O' and D-O” present the rope, which is supposed to be in a plane with the direction of inclination of the mast (X or Y coordinates of the mast - Fig. 4.).

The size of the OD” rope:

ΔL= DO’- DO”, DO”=$\sqrt{D^2+H^2}$, DO’=$\sqrt{(D+V)^2+Z^2}$, Z=$\sqrt{H^2-V^2}$, where do we have:

$$\Delta L=\sqrt{D^2+H^2+2DV} - \sqrt{D^2+H^2} \quad (5)$$

Formula (5) indicates how much the odgon vector must be shortened to bring the mast into a vertical position. Formula (5) can be applied both for the vector and for the corresponding orthogonal coordinates (X, Y). In AMSD the orthogonal coordinates of the sensor are calculated for the corresponding orthogonal directions of the odds (X, Y). The calculation formulas for the vector coordinates will be:

$$\Delta Lx=\sqrt{Dx^2+H^2+2DxVx}-\sqrt{Dx^2+H^2} \quad (6)$$

$$\Delta Ly=\sqrt{Dy^2+H^2+2DyVy}-\sqrt{Dy^{\,2}+H^2} \quad (7)$$

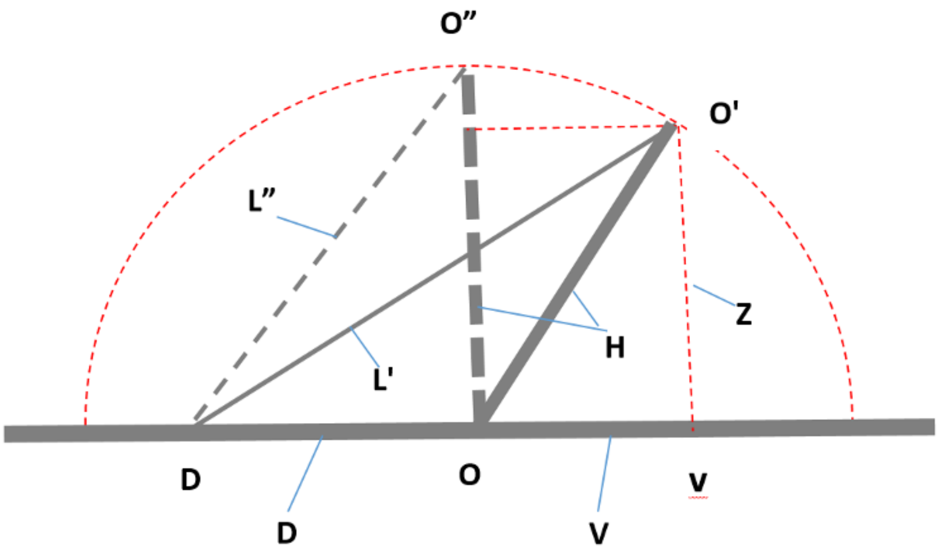


Figure 6. Vertical plan of mast inclination

During the exploitation period, the masts are subjected to several external and internal actions: wind, storm, rain, frost, earthquake, metal fatigue, soil settlement, corrosion, etc. Due to them, the masts have static inclinations and vibrations (dynamic deviations). We will consider the action of the wind on the mast.

After [11] the wind speed changes with time. Speed contains the static permanent component and the variable component. Total wind pressure formula:

$$Psum=Pstat+0{,}5*\rho V^2, \quad (8)$$

where ρ is the air density (kg / m²), V-wind speed m / sec, Pstat- static pressure.

In general, taking into account the constant deviation of the mast from the initial vertical for reasons other than wind, the formula for the summary deviation:

$$D\sum=Dst+Dpv+Ddv, \quad (9)$$

Where Dst-vector static deflection, Dpv-vector permanent deflection from the wind, Ddv-vector dynamic deflection from the wind.

For example, Fig. 7 shows the graph at wind speed of 1.6-1.8m / sec. (AMSD). In Fig. 8 shows the graph of verticality with the maximum amplitudes of vibrations, and Fig.9 shows the same graph with the average amplitudes during the scanning period. From the comparison of these 2 graphs it can be seen that the mast has constant deviations from the norm at the level of 49.85m and dynamic deviations (vibrations) at the levels of 49.85m and 85.85m.

In order to find out the amplitude of the vibrations from the wind actuation (Ddv) it is necessary to fix the diagram at a wind speed of at least 15.0 m / sec. [9,11], in this case the allowed deviation for rope will be L / 500, where L -length of the rope. Or, according to the formula of the normal wind pressure (8), if we change V n times the quantity P changes n^2 times. Formula for wind speed (Vr) will be:

$$Dp=(L/500)(V/15)^2 \tag{10}$$

For example, at a wind speed of 5m / sec., The permitted deviation will be: $L / (500 * 3^2) = L / 4500$.

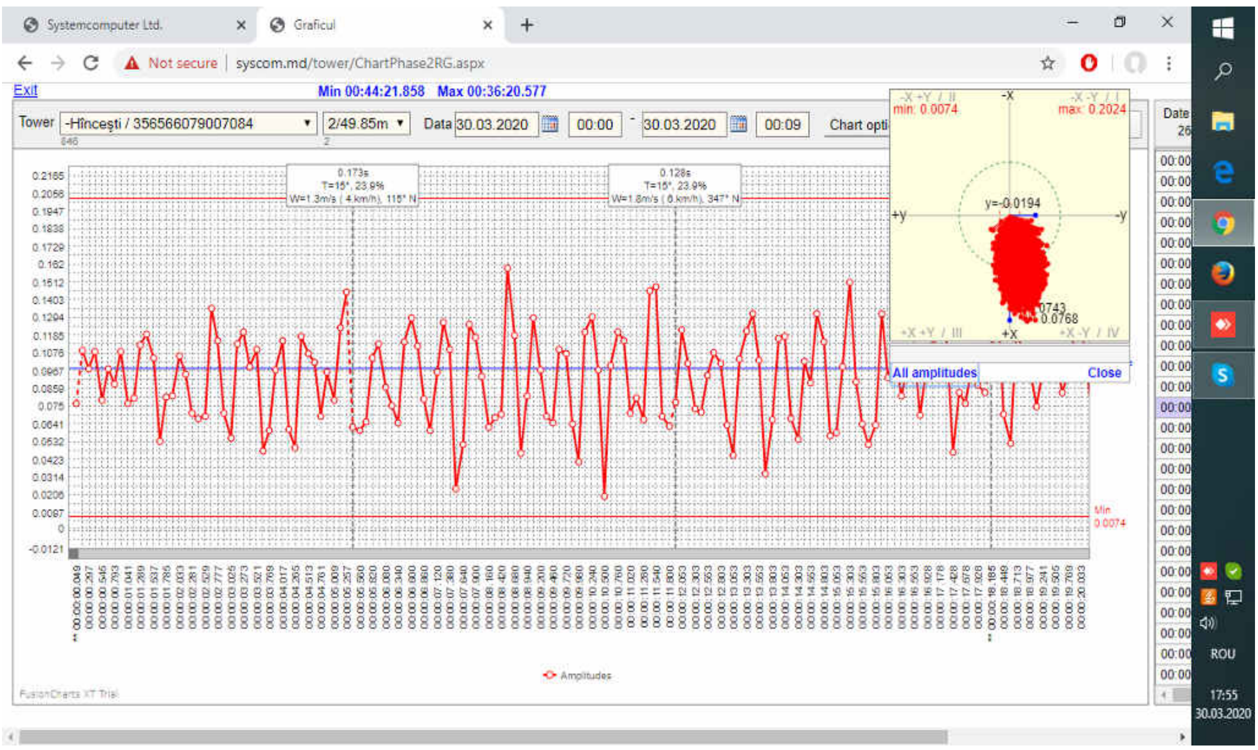


Figure 7. Graf at wind speed AMSD

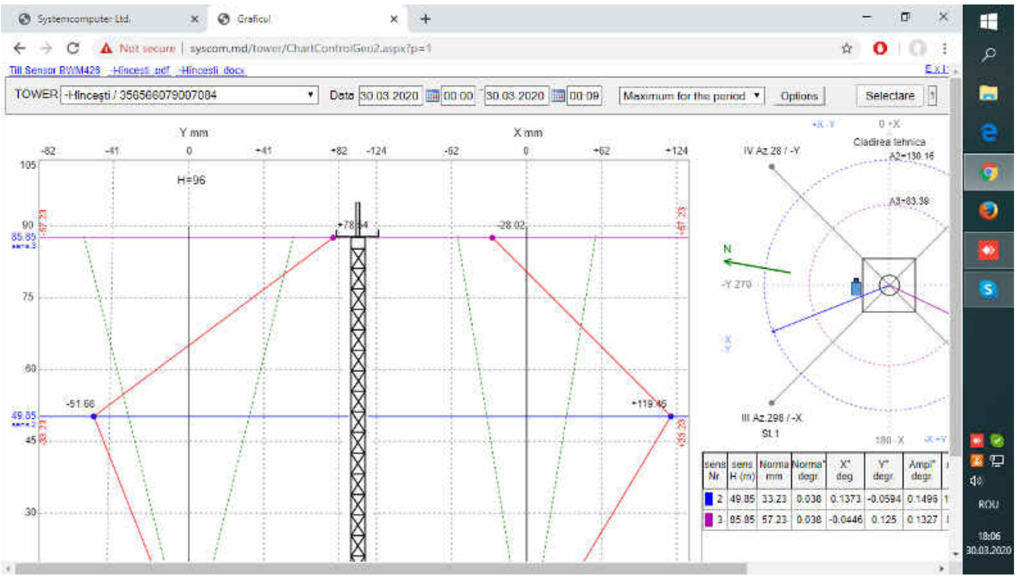


Figure 8. Graph of verticality with the maximum amplitudes

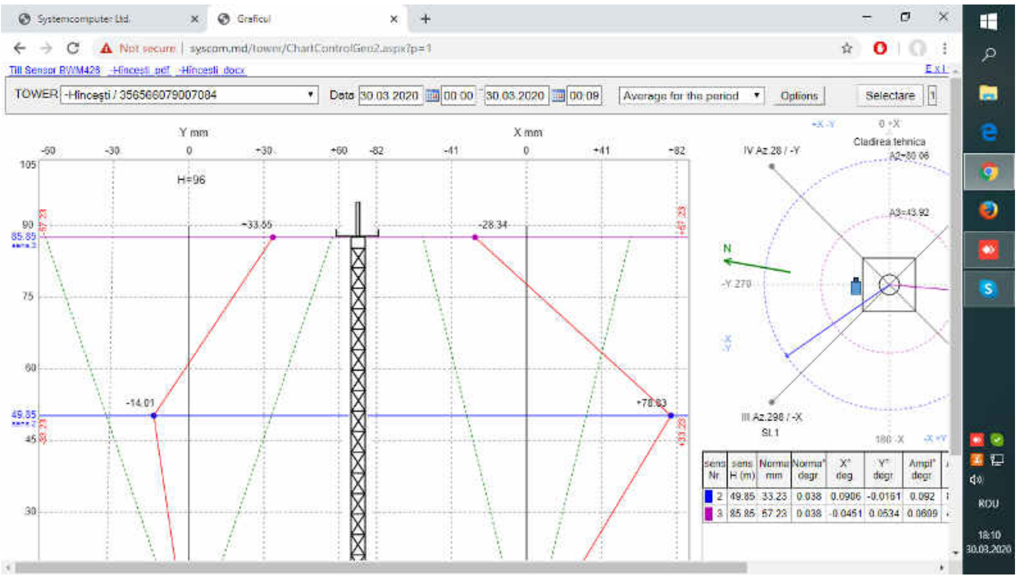


Figure 9. Graf of verticality with the average amplitudes

3. Conclusions

Modern technological advances in the field of electronics and systems engineering, such as MEMS, Mobile Internet, Cloud Computing, SCADA etc., allow developing and implementing effective systems for monitoring such geodetic parameters of masts / towers as verticality and oscillations.

The AMSD system, due to the developed mathematical apparatus, allows you to effectively remotely monitor the static verticality and amplitude of oscillations of masts / towers, as well as determine the necessary parameters for their straightening and elimination of excess oscillations.

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