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POWER SPECTRAL DENSITY ANALYSIS OF VIBRATIONS OF ANTENNAS INSTALLED ON TELECOMMUNICATION MAST

SUMMARY

The effect of wind influence on the construction of a telecommunication mast located in an area with average building height not exceeding 10 meters above ground has been presented in this work. The presented telecommunication mast is a lattice construction equipped with four stay lines. Radio, television and cellular phone network antennas are placed on the mast. Analysis of the mast vibrations was carried out using the ANSYS pack.

***Keywords**: wind influence, PSD analysis, distribution of wind velocity*

ANALIZA PSD DRGAŃ ANTEN ZAMOCOWANYCH NA MASZCIE TELEKOMUNIKACYJNYM

W pracy przedstawiono wpływ oddziaływania wiatru na konstrukcję masztu telekomunikacyjnego zlokalizowanego na terenie zabudowanym o średniej wysokości budynków nieprzekraczającej 10 metrów nad poziomem gruntu. Prezentowany maszt telekomunikacyjny jest konstrukcją kratową wyposażoną w cztery linowe odciągi, na którym zamocowano anteny radiowo-telewizyjne oraz anteny telefonii komórkowej. Analizę wpływu wiatru na konstrukcję przeprowadzono przy wykorzystaniu pakietu ANSYS.

***Słowa kluczowe**: rozkład prędkości wiatru, analiza PSD, oddziaływanie wiatru na konstrukcję*

1. INTRODUCTION

The development of telecommunications technology and the current standards of exploitation and safety of designed communications systems necessitate permanent modernization and development of terrestrial infrastructure devices. With every passing year there is an increase in telephone network transmitters, Wi-Fi networks and terrestrial television transmitters. The correct functioning of each of the devices listed above is related to the antennas placement. In order to obtain the appropriate quality of the transmitted signal, antennas are usually installed on masts or towers, with the average height of neighboring structures being accounted for. The quality of emitted signals (Pokorski 2009) is mainly dependent on the type of antennas used, their distance from the receiving point and, to a lesser degree, on the equipment for amplifying the signal. An increase in the energy gain of the antenna, which is responsible for the quality of emitted signals, results in a smaller angle of view of the antenna. The result of a decrease in the angle of view translates to an increase in the susceptibility of the transmission/receiving system to the effect of vibrations. The angle of view of the antenna can be within a range from one degree vertically and horizontally for parabolic antennas (used to receive satellite or Wi-Fi signals) up to 360 degrees horizontally for omnidirectional antennas. Sector antennas used in cellular telephony and Wi-Fi networks are characterized by a large horizontal angle of view from 90 to approx. 120 degrees and a vertical angle of view of 4 to 10 degrees.

A typical telecommunication mast has a steel lattice or pre-stressed concrete construction made up of several sections reinforced by additional stay lines. Low structures without stay lines are generally called towers. The basic loads of the mast are related to: the weight of its own construction, the weight of elements permanently installed on it, forces acting on stay lines, the effect of wind, temperature change and icing of the construction. Additionally, loads may be incurred through breaking of the stay lines or damage to the antennas installed on the construction. Consideration of each of the disadvantageous external factors requires the elaboration of a model for calculation of loads incurred by the analyzed factor. Models of mast vibrations caused by the movement of the base are described in (Kowal 2009). This work described mathematical models of wind influence on antennas installed on telecommunication mast located in an area with average building height not exceeding 10 meters above ground. The analysis of the mast vibrations was carried out using the power spectral density (PSD) analysis including in ANSYS pack.

Mathematical descriptions of the effect of wind on constructions that are currently in use (Levy 1976, Sockel 1994, Businger *et al.* 1971) are supported by experimental studies. These models based on spatial correlation (Davenport 1961) may be used only for analyses under typical atmospheric conditions. The design of new constructions requires the consideration of structure loads caused by operation in extreme conditions. Guidelines regarding the selection of parameters for these models should be sought in standards prepared for a strictly defined type of construction (in Poland – Polish norm).

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2. MATHEMATICAL MODELS OF WIND BEHAVIOR

A typical vertical wind profile describes the wind velocity function depending on the height above ground level taking into consideration the shape of the terrain. Several models describing the vertical distribution of wind velocity are presented in literature. The model most commonly used is the wind velocity distribution described by the equation (Sockel 1994):

$$v_z(z) = \frac{v_m}{\ln\frac{z_{10}}{k_p}} \ln\frac{z}{k_p} \tag{1}$$

where z is the height above ground level. According to (Businger *et al.* 1971), $k_p = 0.4m$ is defined as the value of the parameter of surface coarseness. The parameter v_m is the constant component of wind velocity at a height of z_{10} = 10 m. The description of the wind profile introduced here is mainly used in simulations of the effect of wind on structures. In the case where a new structure is designed, the polish standard PN-77/B02011 recommends using a standardized model described by the dependency:

$$v_z(z) = v_{ma}\sqrt{C_e(z)} \tag{2}$$

where C_e is the coefficient of exposure accounting for the effect of the terrain on the load incurred by air flowing around the structure. This coefficient can be determined from the formula:

$$C_e(z) = k\left(z/h_0\right)^{2\alpha} \tag{3}$$

The k, h_0 and α parameters occurring in equation (3) are dependent on the type of terrain. According to the polish standard PN-B-03204, three types of terrain can be distinguished within the territory of Poland: open terrain, designated by the letter A, developed terrain with average building height not exceeding 10 m, designated as B, and developed terrain with average building height exceeding 10 m, designated by the letter C. The parameters necessary for determining the coefficient of expositions are presented in Table 1.

Table 1

Parameters for coefficient determination

Type of terrain	A	B	C
k	1	0.8	0.7
h_0	10	18	32
α	0.14	0.19	0.24

Assuming that the considered structure is found in the Silesian Voievodeship terrain with average building height not exceeding 10 m, according to the PN-B-03204 standard, the limit of wind velocity is equal to v_{ma} = 22 m/s. The model of the mast that has been introduced according to the standard assumes that the structure will only work under limit conditions once, during its entire period of exploitation. That is why the calculation model based on formula (1) will be used for further calculations, where a wind velocity of v_m = 15 m/s has been assumed. A graphs of the functions describing vertical wind velocity distribution has been shown in Figure 1.

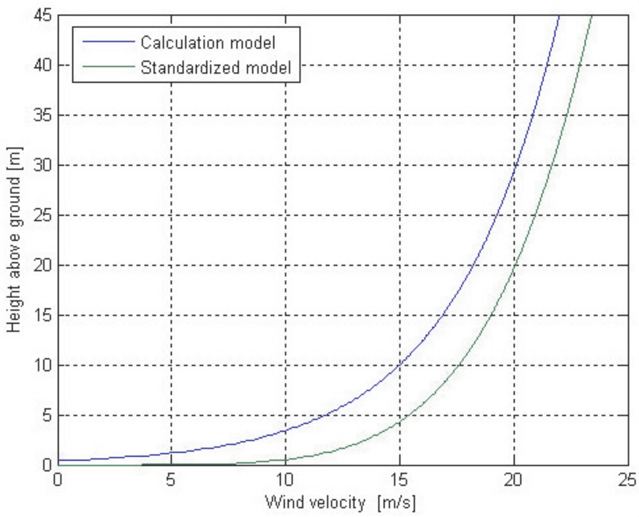


Fig. 1. Distribution of vertical wind velocity

The equation describing the horizontal wind profile should account for static and dynamic effects of wind on the structure, which is why the equations met with in literature usually contain a separate description for the constant and variable components of wind pressure.

The constant component of wind velocity v_m causes a constant force to be exerted on the structure by the wind. The value of this force can be calculated using the formula:

$$F_m = c_x \rho_p \frac{{v_m}^2 \cdot A_p}{2} \tag{4}$$

where the coefficient of wind resistance c_x = 2.6, air density ρ_p = 1.29 kg/m^3 and cross-section areas of the element of the structure perpendicular to the direction of the wind have been designated as A_p.

The variable component of the velocity is described by a stochastic process, the spectral density of which, according to the Davenport model (Levy 1976), has the form of:

$$S_v(f) = 4v_s^2 f^{-1} \frac{\psi^2}{(1+\psi^2)^{4/3}} \tag{5}$$

In equation (5) f is a frequency, and ψ is a non-dimensional variable described by the formula $\psi = 1200\, f/v_m$.

The parameter v_s, with a physical dimension of velocity, can be determined from the dependency:

$$v_s = \frac{v_m}{2.5\ln\frac{z_{10}}{z_0}} \tag{6}$$

where z_0 = 0.05 m was assumed on the basis of the considerations presented in (Gawroński 1992). The formula describing the spectral density of the variable component of exerting on structure can be written as:

$$S_F(f) = \left(2F_m / v_m\right)^2 S_v(f) \tag{7}$$

The introduced mathematical model of excitation makes it possible to simulate a typical wind influence on a structure. In the case of newly designed constructions according to the PN-B-03204 standard, calculations are to be carried out for limit parameters. The standard characteristic load p_k per unit area is defined as the product of the characteristic pressure coefficient q_k, the coefficient of exposition C_e determined using equation (3), the aerodynamics coefficient C and the gust effect coefficient β corresponding to the dynamic component:

$$p_k = q_k C_e C \beta \tag{8}$$

Coefficients q_k and C can be read directly from tables from PN-77/B02011 norm. In the case of the gust coefficient β, its determination requires the determination of the structure's susceptibility to the dynamic effects of wind. The determination of whether the structure is susceptible to dynamic effects or not is possible using the plot shown in Figure 2 for known period of the structure's free vibrations

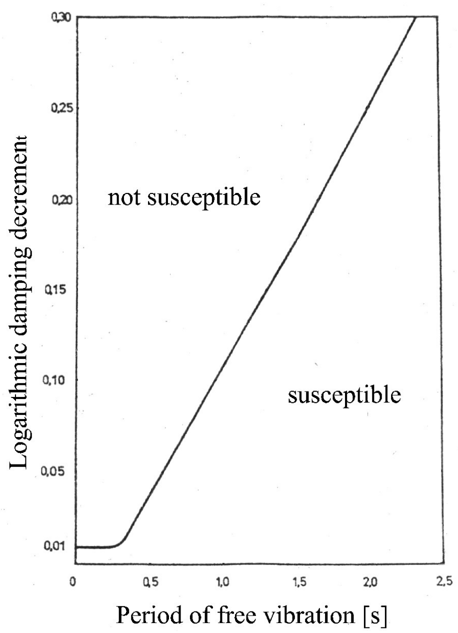


Fig. 2. Division of constructions in terms of dynamic wind effect PN-77/B02011

and a non-dimensional damping coefficient. In the case of steel constructions, the logarithmic damping decrement takes values from 0.02 for welded full-walled constructions to 0.06 for lattice constructions. Concrete constructions are characterized by a decrement higher than 0.1 for prestressed constructions to 0.2 for reinforced concrete prefabricates. The last group of structures are a brick or wood construction, for which the value of the logarithmic damping decrement is accepted to be 0.3 and 0.15 respectively.

For constructions that are not susceptible to the effect of wind, the gust effect coefficient β is assumed as equal to 1.8. For constructions susceptible to the effect of wind, this coefficient can be determined from the formula:

$$\beta = 1 + \psi_e \sqrt{\frac{r}{C_{eh}}(k_b + k_r)} \tag{9}$$

where C_{eh} is the coefficient of exposition accepted for the entire height of the mast, ψ_e is the coefficient of the peak load value, r is the coefficient of terrain roughness and k_b, k_r are successive coefficients of turbulent effect with non-resonant and resonant frequencies.

3. ANALYSIS OF THE WIND INFLUENCE ON THE TELECOMMUNICATION MAST CONSTRUCTION

The mast considered in this article is a steel lattice structure with a height of 45 m consisting of five sections comprised of forty one segments. The first three sections are comprised of twenty-three segments made from angle bars of various dimensions. The base of the first section is a square with a side length of 2.04 m. The upper cross-section of the third section has the shape of a square with a side of 0.726 m. The fourth and fifth sections are composed of another 18 segments with a shape of rectangular prisms with various heights. Eighteen antennas with a total mass of 800 kg were installed on the mast from a height of 25 m. The structure of the mast was reinforced by four asymmetrically placed stay lines fixed at the base of the third section. The total mass of the mast along with stay lines and the upper platform with a mass of 300 kg is equal to approx 5400 kg. The ANSYS Multiphysics pack was used for numerical calculations. Using available mast documentation, a geometric model of the structure was created by defining the base points and lines representing angle bars comprising the lattice. The BEAM4 element was used to model the bars of the lattice construction. The mast model was completed with the introduction of MASS21 elements for modeling antennas. Stay lines were modeled using LINK8 elements, with consideration of initial line tension. The finite element model of the considered telecommunications mast is presented in Figure 3.

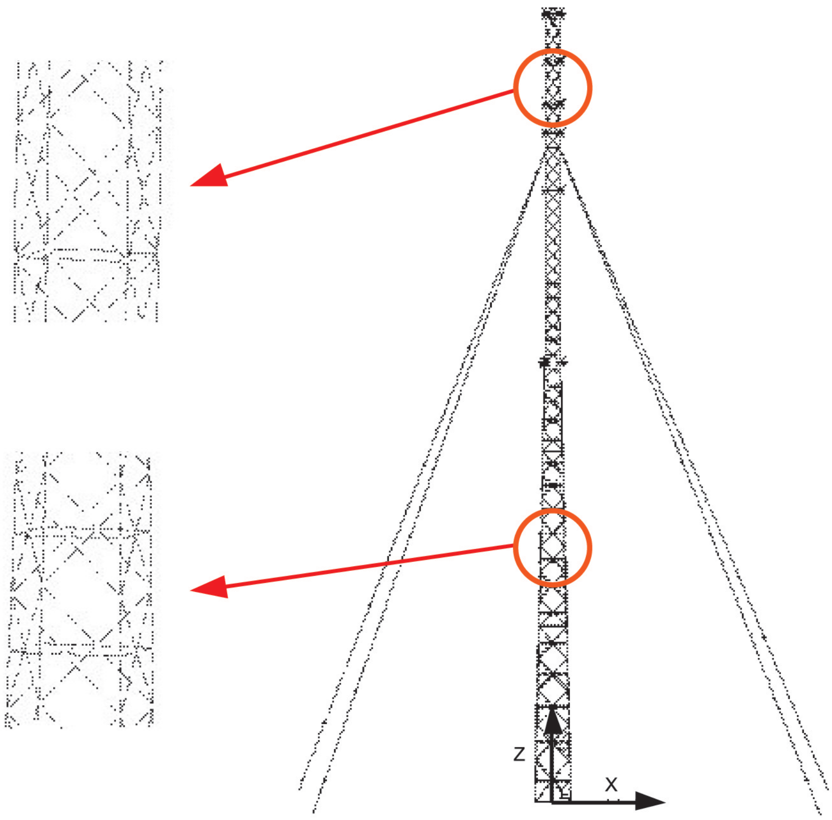


Fig. 3. View of the telecommunication mast structure

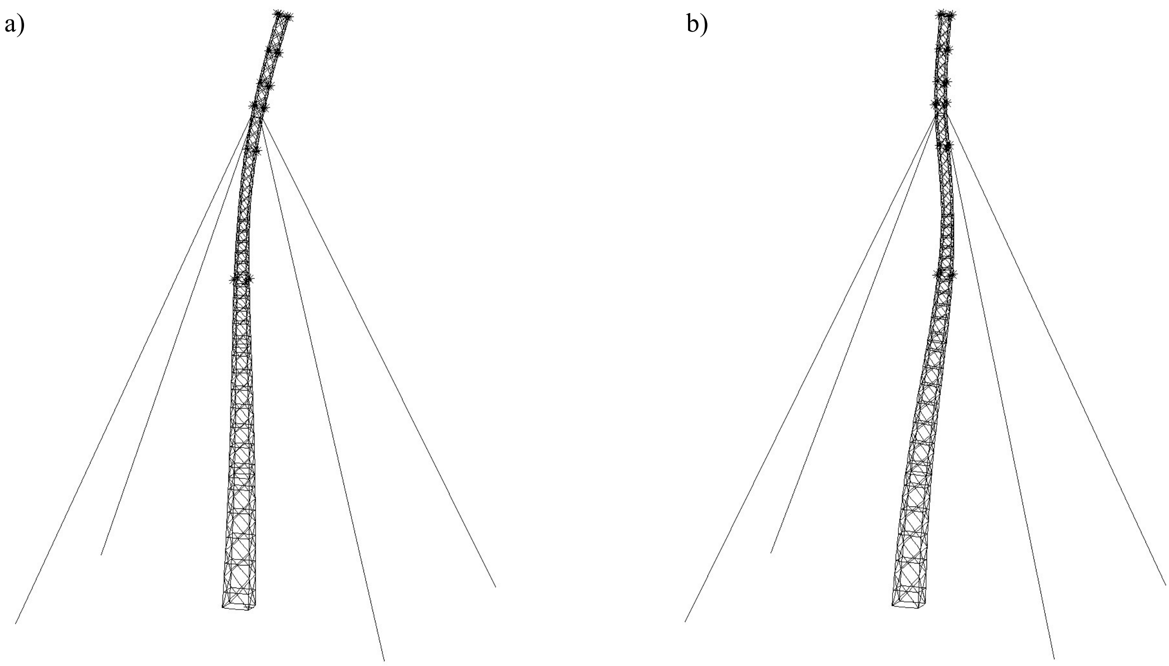


Fig. 4. Mode shapes of mast vibrations: a) first mode; b) second mode

Analysis of mast vibrations began with determination of the natural frequencies modes. Modal analysis was carried out using the Lanczos method (ANSYS 2011). The first and second modal shapes are presented in Figure 4. The corresponding frequencies were equal to 2.19 Hz and 3.15 Hz. The analyzed structure has a steel lattice construction, which is why the non-dimensional modal damping coefficient is accepted from range 0.02 to 0.06. The model written as formula (7) was used for analysis of the effect of wind on the construction of the mast. An exemplary power spectral density plot of the variable component of wind velocity determined at a height of 10 m above ground level is shown in Figure 5.

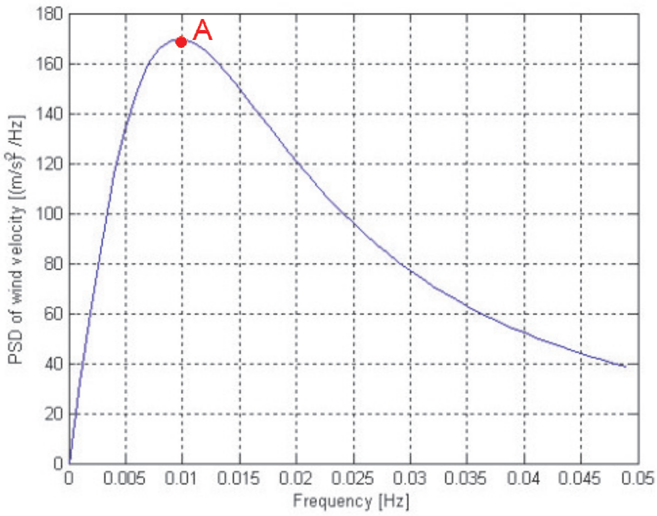


Fig. 5. PSD of wind velocity at z_{10}

The maximum value of PSD wind velocity (marked as A in Fig. 5) can by calculated as fallows:

$$(S_v)_{\max} = \frac{317.89}{\left(\ln \frac{z_{10}}{z_0}\right)^2} v_m \approx 169 \,(\mathrm{m/s})^2 / \mathrm{Hz} \qquad (10)$$

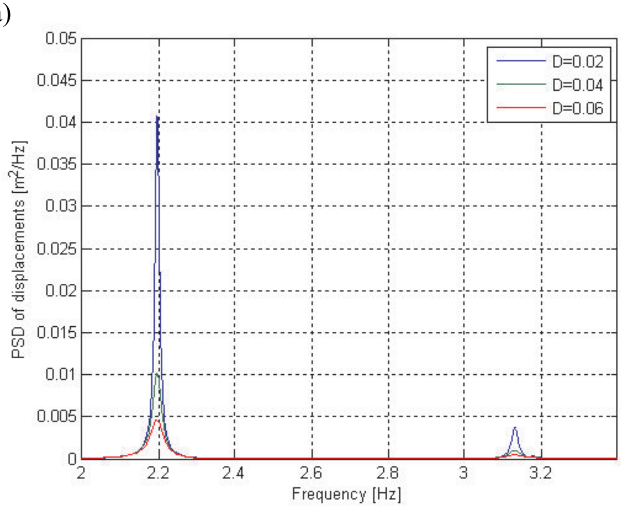
The standard deviation of wind velocity calculated as a square rot of integral of PSD function (5) over infinity interral was equal can be determined from:

$$\sigma_v = \frac{0.98}{\ln \frac{z_{10}}{z_0}} v_m \approx 2.8 \,\mathrm{m/s} \qquad (11)$$

Evaluation of the load of the mast structure resulting from the flow of air around it requires consideration of the vertical and horizontal wind profiles derived earlier. Assuming that the angles between the wind velocity vector and the accepted X and Y axes of the structure model are equal, the loads of elements being part of the modeled mast were determined. Assuming the values of a logarithmic damping decrement of 0.02, 0.03 and 0.06, the power spectral density analysis of displacements and rotations was carried out. Exemplary PSD plots for the selected antenna installation point at a height of 45 m are shown in Figure 6.

The analysis carried out allowed for the determination of standard deviations of displacements and rotations of antennas installation. The result of calculation are shown in Table 2. Calculations were carried out for a logarithmic damping decrement equal to 0.06. The standard deviations presented in the Table 2 show the effect of wind influence on antenna movement.

a)



b)

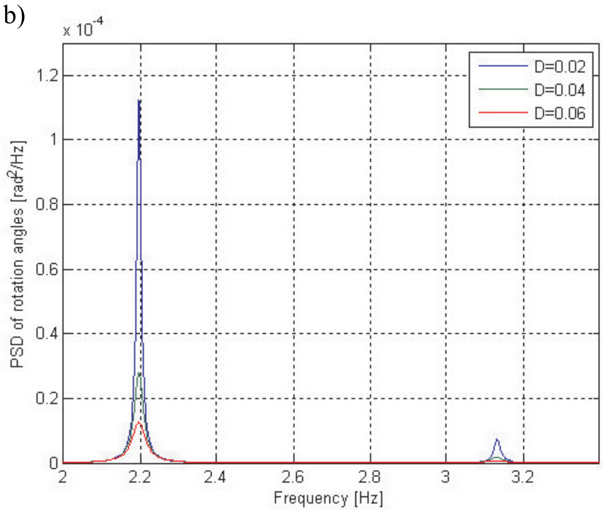


Fig. 6. PSD plots of a) displacement along X axis; b) rotation around the X axis for the antenna installation point at z = 45 m

Table 2

Standard deviations of displacements and rotations of antenna installation

Height of antenna installation [m]	Standard deviations of displacements:	
	along X axis [cm]	along Y axis [cm]
25	$\sigma_x = 1.26$	$\sigma_y = 1.24$
35	$\sigma_x = 0.93$	$\sigma_y = 0.88$
37.5	$\sigma_x = 0.94$	$\sigma_y = 0.64$
40	$\sigma_x = 1.20$	$\sigma_y = 0.58$
42.3	$\sigma_x = 1.80$	$\sigma_y = 0.66$
45	$\sigma_x = 2.66$	$\sigma_y = 0.86$

Height of antenna installation [m]	Standard deviations of rotations:		
	around X axis $\times 10^{-1}$ [^{o}]	around Y axis $\times 10^{-1}$ [^{o}]	around Z axis $\times 10^{-1}$ [^{o}]
25	$\sigma_{\varphi x} = 0.20$	$\sigma_{\varphi y} = 0.21$	$\sigma_{\varphi z} = 0.13$
35	$\sigma_{\varphi x} = 0.56$	$\sigma_{\varphi y} = 0.77$	$\sigma_{\varphi z} = 0.60$
37.5	$\sigma_{\varphi x} = 0.56$	$\sigma_{\varphi y} = 1.20$	$\sigma_{\varphi z} = 1.44$
40	$\sigma_{\varphi x} = 0.59$	$\sigma_{\varphi y} = 1.43$	$\sigma_{\varphi z} = 1.17$
42.3	$\sigma_{\varphi x} = 0.58$	$\sigma_{\varphi y} = 1.76$	$\sigma_{\varphi z} = 0.76$
45	$\sigma_{\varphi x} = 0.61$	$\sigma_{\varphi y} = 1.86$	$\sigma_{\varphi z} = 0.21$

Table 3

Standard deviations of displacements and rotation angles of antennas installation mounted at a height of 45 m for various damping coefficients

Logarithmic damping decrement	Standard deviations of displacements:		Standard deviations of antenna rotations:		
	along X axis [cm]	along Y axis [cm]	around X axis $\times 10^{-1}$ [^{o}]	around Y axis $\times 10^{-1}$ [^{o}]	around Z axis $\times 10^{-1}$ [^{o}]
0.02	$\sigma_x = 3.7$	$\sigma_y = 1.53$	$\sigma_{\varphi x} = 0.98$	$\sigma_{\varphi y} = 2.73$	$\sigma_{\varphi z} = 2.9$
0.04	$\sigma_x = 2.95$	$\sigma_y = 1.07$	$\sigma_{\varphi x} = 0.72$	$\sigma_{\varphi y} = 2.11$	$\sigma_{\varphi z} = 2.3$
0.06	$\sigma_x = 2.66$	$\sigma_y = 0.86$	$\sigma_{\varphi x} = 0.61$	$\sigma_{\varphi y} = 1.86$	$\sigma_{\varphi z} = 2.1$

The damping coefficient, dependent on the method of installation of individual elements of the construction, significantly affects the PSD value. In Table 3, standard deviations for three assumed values of the damping decrement are presented.

4. SUMMARY

The analysis that was carried out allows for the verification of antenna installation points for improving the conditions of the construction's exploitation and improving the quality of emitted signals. Taking into account the obtained values of standard deviations of the mast construction vibrations caused by the wind are small. The asymmetrical fixing of stay lines and asymmetrical placement of antennas causes differences in the values of standard deviations of displacements and rotations determined at the points of antenna installation. The simulation of the mast that was carried out suggests installation of sector antennas susceptible to vertical deviations in the lower parts of the mast and at a height from 37 m to the point of stay line fixation. Parabolic antennas used in cellular telephony and Wi-Fi networks should be installed near the top of the mast due to their horizontal and vertical angle of view and recommended high installation height.

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