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УТОЧНЕННЯ КОЕФІЦІЄНТА ДИНАМІЧНОСТІ ПРОМІЖНОЇ БАШТОВОЇ ОПОРИ П110-6 ПРИ ДІЇ ПУЛЬСАЦІЙНОЇ СКЛАДОВОЇ ВІТРОВОГО НАВАНТАЖЕННЯ

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Анотація. У статті виконано динамічний розрахунок металевої проміжної опори П110-6 повітряної лінії (ПЛ) 110 кВ на дію пульсаційної складової вітрового навантаження. Метою динамічного розрахунку ґратчастих опор ПЛ на вітровий вплив є аналіз сталих коливань опори у вітровому потоці. При цьому характеристики вузлових переміщень, внутрішніх сил і напружень визначаються у скінченних елементах (решітці та поясах) роздільно від дії середньої та пульсаційної складових вітрового навантаження. Наводиться методика та результати динамічного розрахунку стержня еквівалентної жорсткості. Приділено увагу основним проблемам, які можуть виникнути при переході від просторової моделі опори до стержня з рівноміцним перерізом. Розглядається ряд питань, пов'язаних з уточненим визначенням коефіцієнта динамічності. На підставі розрахунку та узагальнення отриманих результатів виконано детальне порівняння коефіцієнтів динамічності по секціях проміжної опори з коефіцієнтами динамічності стержня еквівалентної жорсткості при дії пульсаційної складової вітрового навантаження.

Ключові слова: повітряна лінія електропередавання, проміжна опора, коефіцієнт динамічності, просторова модель, стержень еквівалентної жорсткості.

УТОЧНЕНИЕ КОЭФФИЦИЕНТА ДИНАМИЧНОСТИ ПРОМЕЖУТОЧНОЙ БАШЕННОЙ ОПОРЫ П110-6 ПРИ ДЕЙСТВИИ ПУЛЬСАЦИОННОЙ СОСТАВЛЯЮЩЕЙ ВЕТРОВОЙ НАГРУЗКИ

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Аннотация. В статье выполнен динамический расчет металлической промежуточной опоры П110-6 воздушной линии (ВЛ) 110 кВ на действие пульсационной составляющей ветровой нагрузки. Целью динамического расчета решетчатых опор ВЛ на ветровое воздействие является анализ установившихся колебаний опоры в ветровом потоке. При этом характеристики узловых перемещений, внутренних сил и напряжений определяются в конечных элементах (решетки и поясах) раздельно от действия средней и пульсационной составляющих ветровой нагрузки. Приводится методика и результаты динамического расчета стержня эквивалентной жесткости. Уделено внимание основным проблемам, которые могут возникнуть при переходе от пространственной модели опоры к стержню с равнопрочным сечением.

Рассматривается ряд вопросов, связанных с уточненным определением коэффициента динамичности. На основании расчета и обобщения полученных результатов выполнено детальное сравнение полученных коэффициентов динамичности по секциям промежуточной опоры с коэффициентами динамичности стержня эквивалентной жесткости при действии пульсационной составляющей ветровой нагрузки.

Ключевые слова: воздушная линия электропередачи, промежуточная опора, коэффициент динамичности, пространственная модель, стержень эквивалентной жесткости.

DYNAMICITY COEFFICIENT REFINEMENT FOR INTERMEDIATE SUPPORT P110-6 UNDER THE ACTION OF THE PULSATION COMPONENT OF THE WIND LOAD

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Abstract. In the paper is defined a dynamic calculation of the steel i ntermediate overhead power transmission line support P110-6 (OHTL) 110 kV to action pulsation component of the wind load. The purpose of dynamic calculation of lattice overhead line supports to the wind influence is an analysis of steady-state oscillations foothold in wind flow. In this case, the characteristics of nodal displacements, internal forces and stresses are determined in finite elements (lattice and belts) separately from the effects of moderate and pulsation components of the wind load. The technique and results of the dynamic analysis of the equivalent stiffness rod are shown. Paid attention to the main problems that may arise during the transition from the spatial model of the support to the rod with equal strength section. Considering a number of issues related to clarifying the definition of the dynamicity coefficient. On the basis of the calculation and generalization of the results carried out a detailed comparison of the sections' dynamicity coefficients for the intermediate support with dynamicity coefficients of the equivalent stiffness rod under the action of pulsation component of the wind load.

Keywords: overhead power transmission line, intermediate support, dynamicity coefficient, space model, equivalent stiffness rod.

Introduction

Wind load for most structures, including power lines and supports (considering wind load on the wire and rope), is one of the significant [1, 2].

In all cases of the wind load determining to the structure the dynamic component of the wind flow is considered as an static additive to an average component and does not fully describe the change in load over time, and therefore practically impossible to study the dynamic behavior of the structure.

To each «class» of overhead line supports to which made the division in [9], belong to the structure with different heights, with different base and made under various schemes, therefore shown in the rules [4, 8], the dynamicity coefficient taken with a margin to cover all inaccuracies that may arise in this approach to the definition of pulsation component of the wind pressure. As a result of the wind load overestimation occurs, which leads to weighting support structure.

Thus, considering the fact that currently accepted position of the individual building of overhead line supports under specific weather conditions and the fact that the design of the OHTL is carried out in accordance with [4, 5, 19], the question arises: will be fair the dynamicity coefficient, shown in the standards for steel intermediate supports, in determining of the pulsation component of the wind load.

The general solution of the problem of structures forced vibrations

The wind represented irregular, a whirl of air and, in this connection, at the decision of the majority of applied problems including problems of building dynamics, the wind speed are consider as casual vector process which, as usual, are described by the spatial and temporary statistical characteristics: mean value, dispersion, mutual spectral and correlation functions [15]. At such approach impact of the wind $W(z, t)$ to buildings and structures also may to be consider as stochastic function of time t and spatial coordinate $z = (z_1, z_2, z_3, \ldots)$. At this $W(z, t)$ are divided to average $W_m(z)$ and pulsation $W_p(z, t)$ components:

$$W(z,t) = W_m(z) + W_p(z,t). \qquad (1)$$

Thus, as the initial parities using for the decision of a problem about forced vibrations of structures at action of the pulsation component of the wind load, was accepted linear equations of a structural movement which generally registered in a sort:

$$m(z)\cdot\ddot{u}(z,t) + \Gamma(\ddot{u}(z,t)) + L_x(u(z,t)) = W(z,t) \ (2)$$

and boundary conditions correspond to its:

$$B(u,\dot{u}) = 0, \qquad (3)$$

where $u(z, t)$ – the general vector of dynamic movements in a point with coordinates *of* $z = (z_1, z_2, z_3)$; t – time; $m(z)$ – mass; $\Gamma(\ldots)$ and $L_x(\ldots)$ – the linear differential operators describe according to dissipative and elastic properties of the structure; $W(z, t)$ – the general vector of a wind load; $B(\ldots)$ – the linear operator correspond to conditions on the structural border and to conditions of mating are more its than separate elements.

Usually at the decision of dynamic problems of the structural mechanic for the description of dissipative properties of the structure using the Fokht hypothesis [17]:

$$\Gamma(u(z,t)) = \gamma\cdot\dot{u}(z,t), \qquad (4)$$

where γ – the factor describing of the energy dissipation.

Generally the vector *of* $u(z, t)$ included displacement and angles of rotation, and the vector *of* $W(z, t)$ – operating forces and moments.

At the decision of applied problems the wind load *of* $W(z, t)$ are consider as vector casual stationary process which in this case could be spread out abreast by Fourier. And the decisions of a regional problem are in a sort of the Fourier number:

$$W(z,t) = \sum_i w_i^p(z)\cdot \sin\omega\, t_i + w_i^m(z)\cdot \cos\omega\, t_i. (5)$$

The determination of the dynamic structure response

The purpose of the dynamic calculation to the wind impact are the analysis of the structural establish vacillating in the wind flow. Thus likelihood characteristics of nodal displacement, internal forces or strengths determining in finite elements separately from action of average and pulsation components of the wind load [18].

It are necessary to notice that determination *of* $W_m(z)$ are based on results of the statistical analysis of maxima (monthly or annual) an average speed of the wind for more enough (> 25 years) a time interval.

Design (maximum) dynamic reaction of the structure determining as peak value of displacement u_p defined with more enough degree of security:

$$u_p = \sigma_u \cdot \gamma_g, \qquad (6)$$

where σ_u – a standard of displacement; γ_g – a security coefficient of the wind load pulsation component.

Theoretically, the coefficient γ_g could be determine from the condition, that reaction u with the set probability σ_u did not exceed the design value u_p. In practice value of this coefficient selecting on the basis of expert estimations and operating experience of buildings and structures. In standards of the various countries regulating the wind impacts, γ_g changed from 2.5 to 4.0 [4, 8, 19]. Design parities in [3] received for $\gamma_g = 3.0$.

The reaction standard σ_u of the structure determining as a result of the decision of the correspond dynamic regional problem. As a rule, this calculation defining numerically and in linear statement.

The pulsation component of the wind load *of* $W_p(z, t), z$ operate in everyone point on a structural surface, is proportional to the sum of elementary impacts $\Delta w_{p,i}$ determined on all frequency range. Thus, in linear statement of the reaction determination of structures at action of the pulsation component of the wind load are reducing to the decision of the forced vibration problem of continual systems or systems with more degrees of freedom at impacts $\Delta w_{p,i}$ and superposition of received decisions for all $i = 1, 2, 3...$

Total value of the structural reaction (displacements, forces, strengths) determined by the equation [14]:

$$X = X^s \pm X^d, \tag{7}$$

where X – size of the required factor; X^s – the value of the consider factor determining by action of the static components of the wind load; X^d – the same from action of the pulsation component of the wind load.

At determination of the total effect of the wind impact it are necessary to select that sign which are more adverse [13]:

$$X = X^s + sign\left(X^s\right) \cdot X^d. \tag{8}$$

The dynamic calculation of the OHTL intermediate support P110-6

The purpose of this work is dynamic calculation of the steel intermediate support P110-6 with the pulsation component of the wind load and determination the dynamicity coefficient.

The dynamic calculation are carry out in two ways: by means of the program complex «SCAD» and by means of the approach technique according to [3, 16].

The dynamic calculation of the support P110-6 using the program complex «SCAD»

The intermediate support P110-6 structurally represented steel spatial pole, with narrow base, height H = 35.0 m (fig. 1). Wigth at the base – 2.8 m. The support consisted of five sections. Belts, inclined braces, division bars and diaphragms of support sections was made from the single steel angle profile. Joints of elements in knots with bolts.

The overall view of the intermediate support of the tower type of OTPL 110 кV are show in figure 2.

For the dynamic calculation the normal operating mode are accepted: wires and ropes was not off and free from ice; the wind are direct along axes of cross frames [10]. The wind pressure to each wire is 1 470 kg, to the rope – 920 kg. The support calculation is defining to loads for the 5th wind region.

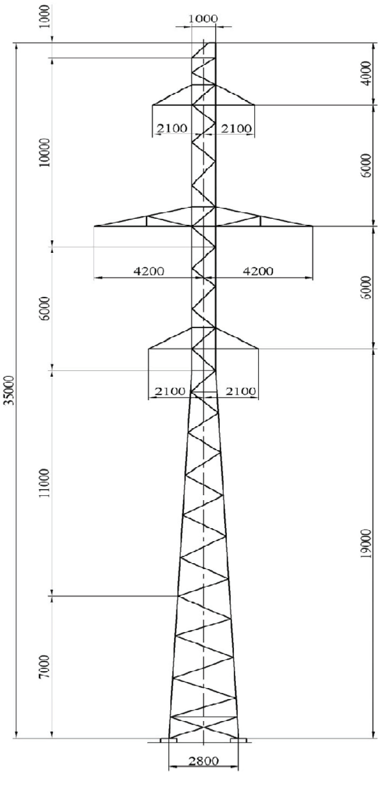

Figure 1. The geometrical scheme of the tower type support P110-6.

Figure 2. The general view of the intermediate support P110-6.

So, in the course of calculation had been receiving forces and displacements by sections of the support P110-6 from the static component action of the wind load X^s and from the joint action of the static and dynamic component of the wind X by the equation (8).

Further by sections of the support have been defining the dynamicity coefficients K_d, dependent to the relation of force factors and displacements (table 1) by equation:

$$K_d = \frac{X}{X^s}. \qquad (9)$$

More average criterion for determination of dynamicity coefficient K_d for all support is the relation of the maximum displacement of the support's top point from total action of the static and dynamic component of the wind load f to displacements from the static component f_{cm} as in displacements is considering the distribution of forces and stiffness by all support's sections [20, 21]:

$$K_d = \frac{f}{f_{cm}}. \qquad (10)$$

In the bottom line of table 1 are shown the average values of the dynamicity coefficient for the lattice support P110-6.

In figure 3 are shown changing graphs of dynamicity coefficients K_d by height for spatial model of the OHTL support, determined by axial forces and deflections.

Table 1. The value of K_d depend of axial forces and deflections

№ of section	Axial forces N, t			Dynamicity coefficient K_d	Deflections, cm			Dynamicity coefficient K_d
	static component	dynamic component	full		static component	dynamic component	full	
1 section	48,35	24,91	73,26	1,515	0,61	0,33	0,94	1,541
2 section	44,68	23,55	68,23	1,527	2,79	1,67	4,46	1,599
3 section	32,33	20,95	53,28	1,648	4,51	2,91	7,42	1,645
4 section	22,57	15,70	38,27	1,696	9,89	7,08	16,97	1,716
5 section	5,46	4,03	9,99	1,738	13,21	9,71	22,92	1,735
6 section	2,67	2,12	4,79	1,794	19,08	14,36	33,44	1,753
Mean value $k_{d,cp} = X/X^s$				1,653	Mean value $k_{d,cp} = X/X^s$			1,665

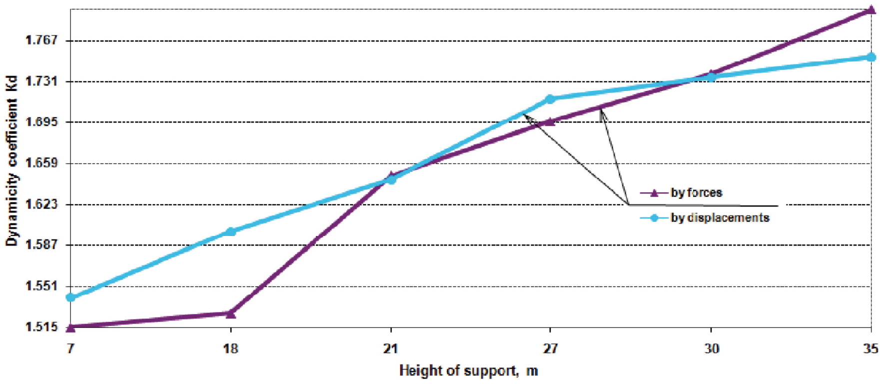

Figure 3. The changing of dynamicity coefficients K_d by height for spatial model of the OHTL support.

The dynamic calculation of equivalent stiffness rod

For creation of such settlement scheme the support was breaking to lots. Within each lot the structure stiffness were considered as a constant, and by the support's height of rigidness are changed from a lot to a lot. Defined the average stiffness of the lots characteristic, masses of the support structure and masses of wires and ropes which are concentrated in the centre of settlement lots. In fig. 4 the rod with equivalent stiffness with the result masses in number of 19.

Were calculated the static components of the wind load (fig. 5) and from the joint action of static and dynamic components of wind (fig. 6) to the intermediate tower support P110-6 which also concentrate in level of the result masses.

The standard value of the dynamic component of the wind load is determined for each mode shapes support in the form of inertial forces applied to the concentration mass in the directions of their possible oscillations [3].

The inertial force (kN), applied to the concentration mass with number *j* with structure's oscillations by *i* own shape determined by the formula:

$$W_p^{ij} = M_j \cdot \xi_i \cdot \eta_{ij} \cdot \nu \,, \qquad (11)$$

where M_j – the concentration mass; ξ_i– the dynamicity coefficient for *i* own shape oscillation; η_{ij}– reduced acceleration of the mass M_j; ν – the coefficient taking into account the spatial correlation of the wind's speed pulsations by support's height.

Reduced acceleration η_{ij} determined by the formula:

$$\eta_{ij} = \frac{a_{ij} \cdot \sum_{k=1}^{r} a_{ik} \cdot W_{mk} \cdot \varphi_k}{\sum_{k=1}^{r} a_{ik}^2 \cdot M_k} \,, \qquad (12)$$

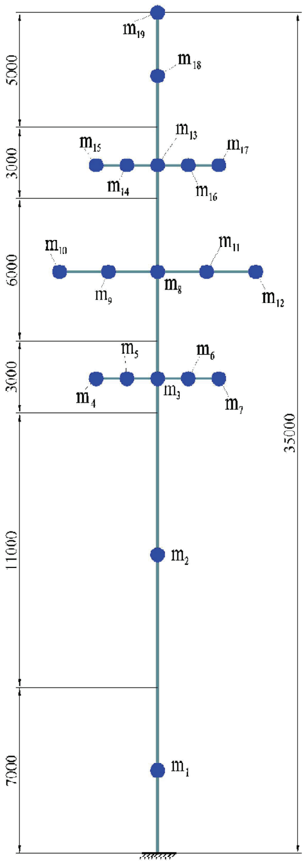

Figure 4. The equivalent stiffness rod with reduced mass.

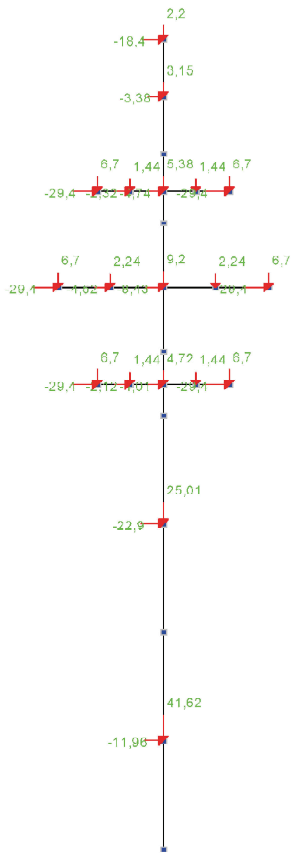

Figure 5. Static component of the wind load $W_m(z)$, kN.

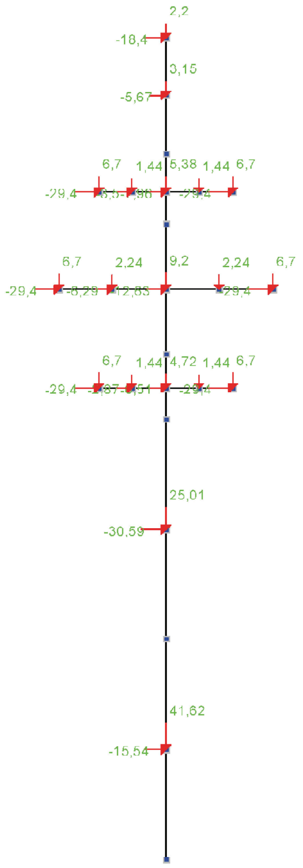

Figure 6. Static and dynamic components of the wind load *W(z,t)*, kN.

where M_k – the concentration mass with number k; a_{ij}, a_{ik} – relative ordinates, which are taken from the eigenvector of the i-th mode shapes; W_{mk} – the normative wind load acting to the k-th mass; φ_k – the pulsation coefficient of the wind's velocity head at the level of the mass M_k; r – number of sections into which broken the OHTL support.

According to [3] in the calculation takes into account only a certain amount of the first forms of natural oscillations, which is determined by the condition:

$$f_s < f_l < f_{s+1}, \qquad (13)$$

where f_s – the technical frequency of the structure's own oscillations; f_l – accepted by [3].

In accordance with the method described above calculates the equivalent stiffness of the rod height of 35.0 m.

Thus, in the process of calculating was obtained the distribution of forces and displacements in sections of the rod model with equal strong section (Table 2) and the dynamicity coefficient K_d by the formula (10).

In the bottom row of Table 2 is shown the mean dynamicity coefficient for the rod with equivalent stiffness a whole.

The calculation of the dynamic wind's impact produced by the 1st form of own oscillations, because the first mode shape coincides with the action of the wind. According to the second form, the system oscillates along the power line. However, in this direction arises supporting act of wires and cables, therefore 2nd mode shape is not taken into consideration [7].

Figure 7 shows variation graphs of the dynamicity coefficient K_d by height of the rod model for the intermediate support P110-6.

Table 2. The value of K_d depend of lateral forces and deflections

№ of section	Lateral forces Q_z, t		Dynamicity coefficient k_d	Deflections, cm		Dynamicity coefficient k_d
	static component	full		static component	full	
1 section	6,56	9,30	1,418	0,10	0,15	1,50
2 section	5,34	7,72	1,446	0,42	0,63	1,50
3 section	3,01	4,63	1,538	0,62	0,94	1,516
4 section	2,38	3,67	1,542	1,31	2,02	1,541
5 section	1,06	1,75	1,651	1,74	2,70	1,552
6 section	0,34	0,58	1,706	2,48	3,86	1,556
Mean value $k_{d,cp} = X/X^s$			1,550	Mean value $k_{d,cp} = X/X^s$		1,528

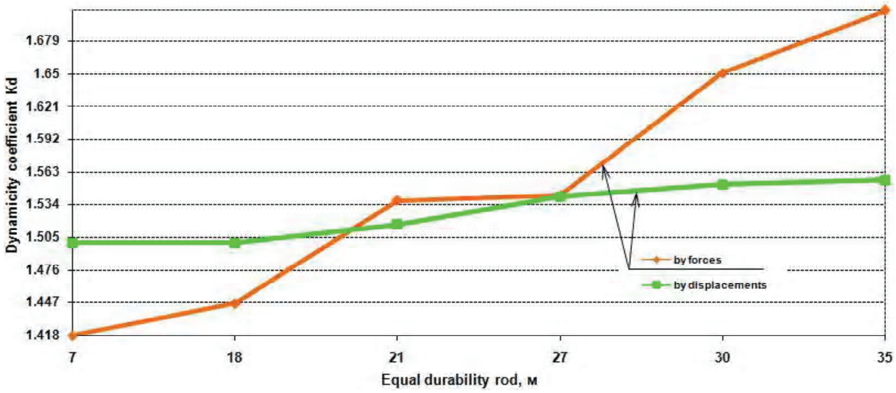

Figure 7. Changing of dynamicity coefficients K_d by height of the equivalent stiffness rod.

Conclusion

1. The dynamic influence of the pulsation component of the wind load W_p to the distribution of forces and displacements in steel tower type supports is 65 % from the average static load W_m.
2. The mean value of the dynamicity coefficient K_d for supports is more rational to determine through the relation of displacements of the support top points.
3. The dynamicity coefficient K_d depend of the support's height: with increase in height of the support increased also values K_d by support's sections.
4. The approach design procedure of OHTL supports to action of the wind provided enough accuracy of received results (around 92 %) which are quite comprehensible at carrying out of engineering calculations.
5. Application of the simplify technique for the determination of the dynamicity coefficient K_d, are described in [3], allows practically without a loss of accuracy (with a margin error ≈ 8 %) of receiving results to simplify algorithm of the dynamic calculation for lattice supports of OHTL to the wind action.

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