Type of the Paper (Article, Review, Communication, etc.)

**DEFORMED STATE OF OHL WIRE TAKING INTO ACCOUNT BENDING RIGIDITY**

**Gimadiev R.SH. 1\*,2**

|  |
| --- |
| **Citation:** Lastname, F.; Lastname, F.; Lastname, F. Title. *Dynamics* **2022**, *2*, Firstpage–Lastpage. https://doi.org/10.3390/xxxxx  Academic Editor: Firstname Lastname  Received: date  Accepted: date  Published: date  **Publisher’s Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.    **Copyright:** © 2021 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/). |

1 Kazan State Power Engineering University; *\*e-mail:* [*gimadievr@mail.ru*](mailto:gimadievr@mail.ru)

2Institute of Mechanics and Mechanical Engineering K.F.I.Z (Kazan); e-mail:[zara-skvortsova@yandex.ru](https://e.mail.ru/compose?To=zara%2dskvortsova@yandex.ru)

**Abstract.** Numerical studies of the dynamics of deformation of the wire of a high-voltage line (VL) of power transmission were based on the hypothesis of an absolutely flexible model, taking into account compressive and tensile forces. In continuation, the influence of the bending stiffness of the wire on the stress-strain state (SSS) of the wire is investigated. Nonlinear equations of wire dynamics are solved based on the finite difference method using an explicit scheme. The limit equilibrium state of the wire is determined by the method of establishing a dynamic problem. On the basis of numerical simulation, the influence of bending stiffness on the shape of the equilibrium state of the wire is determined and the error of the hypothesis of the applicability of an absolutely flexible wire of overhead lines is estimated. Tension forces are also determined when the wire is raised to a given sag height.

*Keywords: power line, numerical experiment, influence of bending stiffness, sag, tension in the wire, assembly force*

**1.Formulation of the problem.**

In [1,2], the simulation of the dynamics of a high-voltage transmission line (HVL) was carried out according to the model of an absolutely flexible system, taking into account tension and compression. In this case, the VL supports were taken absolutely rigid.

In the problems devoted to the study of the interaction of a flowing fluid in a deformable pipe and a thin plate [3-5], bending stiffness is one of the main factors. The issues of designing electric power systems and networks are considered in [6,7]. Accounting for the influence of forces acting on cables and tapes was studied in [8-12]. The question arises of what effect the bending stiffness of the wire has on the stress-strain state. When designing electric power systems, it also becomes necessary to take into account the installation forces on the wires. The smaller the sag of the wire, the more it is necessary to apply mounting forces.

Obviously, by reducing the length of the wire and the modulus of elasticity, it is possible to find the conditions under which the bending stiffness will affect the deformed state of the wire. From physical considerations, apparently, even for a textile thread, you can specify the length at which you need to take into account the bending stiffness.

Thus, the study of the influence of the flexural rigidity of the wire on the stress-strain state and the forces arising when the wire is lifted to a given sag are topical tasks.

Let the flexible wire of an overhead line with a linear density  in the field of gravity move in space under the action of a distributed linear normal load  and a tangential load . The deformation of the flexible system is characterized by the degree of elongation , where  and  - are the lengths of the elements of the flexible system before and after deformation,  - is the relative elongation. For an element of a flexible system with mass , in accordance with the mass conservation law, we have . Obviously, the bending stiffness should reduce the deflection of the wire compared to a perfectly flexible wire, the question is by how much. Below, comparative calculations of the stress-strain state (SSS) of the wire are carried out, taking into account the bending stiffness and the absolutely flexible model of the wire. An important factor is the length of the wire.

The limiting solution of the dynamic problem gives the solution of the SSS of the stationary state of the wire.

The equation of motion of a flexible wire overhead line, taking into account the

bending stiffness of the wire for a plane problem, can be written as

**** (1.1)

where is the bending stiffnes of the wire, is the moment of inertia of the wire with radius  , - is the tension in the wire, - is the modulus of elasticity of the wire,  - are the components the speed of the flexible system element in the projection of the velocity vector  on coordinate axes, ,  is the devlection of the wire, the initial coordinate of the span points  and  is the coordinate of the sag, - linea densite; - relative extension; - lagrangian coordinate; - acceleration of gravity.

The equations of motion (1.1) are solved in a dimensionless form by introducing the following dimensionless parameters: Where

, ,  , 

, , , 

where - is the speed of the wire element;  - wire span length;  - is the mass of the wire span; -installation length of the wire; - reduced modulus of elasticity of the wire material; - characteristic wire tension; - time; -is Newtons parameter. Below, in the notation, we omit the dashes above the parameters.

**2. Scheme for solving the problem**.

The system of equations (1.1), is solved by the finite difference method, the discrete

domain is introduced into consideration



equation (1.1) in dimensionless form is represented as

****. (1.2)

When solving, central differences are used to approximate the derivatives on a grid

shifted by half a step and an explicit finite-difference scheme.

The physical ratio is taken in the form of the Kelvin-Voigt formula

 (1.3)

where - strain rate,  - coefficient of internal friction in the material.

Kinematic relations  and geometric relations

  (1.4)

The initial and boundary conditions for the wire are written as

,  ,

, ,

, , . (1.5)

The results of solving the problem at the integration  step serve as initial and boundary conditions for the next integration step.

The equilibrium state of the flexible wire is obtained as the limiting solution of the

dynamic problem. The choice of the speed correction factor and the stability factor of the

numerical solution is carried out by carrying out numerical experiments on model

problems [9].

Calculations according to (1.2): let the linear density of electrical wires made of aluminum be equal to  ; span length between supports ; the elastic modulus  of a wire with a diameter of .

Below is the calculation of the equilibrium state of a wire weighing 82.69 kg and an installation length of 160.6 [м] without bending stiffness  and taking into account . The value of the maximum deflection *f* = 6.19 м in the middle of the span was  not affected by the bending stiffness. To raise the wire with such a sag on the support, it is necessary to apply a force *T* = 2574 [N].

Figure 1 shows the results of calculations of the deflection of the overhead line, when breaking down the length of the wire into 40 equal parts.

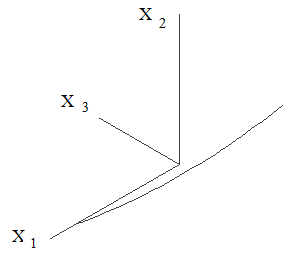


Fig. 1 Equilibrium wire shape,  [м], max  м

A numerical experiment is being carried out to determine the equilibrium state of the overhead line wire, the deflection max *f* and the mounting force *T* when lifting the wire, with a variation in the mounting length .

The calculation results are summarized in table 1.

Table 1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| [м] | 160,1 | 160,2 | 160,4 | 160,6 |
| *f* [м] | 3,18 | 3,92 | 5,11 | 6,19 |
| *T* \*103[Н] | 5,086 | 4,081 | 3,139 | 2,574 |

In accordance with Table 1, using the Lagrange polynomial, a graph of the dependence of the sag (deviation of the wire from the wire connection line) and the necessary mounting force to raise the wire to the specified sag was plotted. And according to the graph fig. 2, it is possible to predict for the required amount of wire sag in the range of (3.18-6.19) meters the required tensile force when lifting the wire.

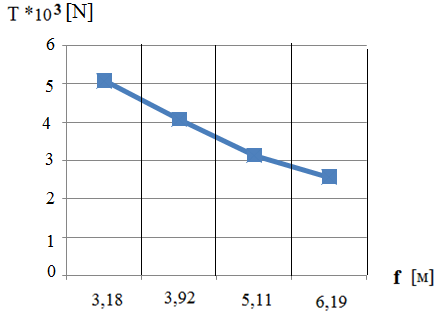


Fig. 2 Dependence of the mounting force on the sag of the wire

In accordance with the calculations, the bending stiffness of the wires does not affect the stress-strain state of long wires of the order of 160 м.

The question is raised, and with a decrease in the length of the wire and the modulus of elasticity, is it necessary to take into account the bending stiffness and does this affect the sag of the wire?

Below, the deflection of an overhead line wire with a length *L*1= 1,0 м is calculated, taking into account the bending stiffness . With the following values of dimensional parameters: wire length *L*1= 1,0 м; diameter  м ; modulus of elasticity *E*= 8073 N; Linear weight  = 0.5127 kg/м.

Values of dimensionless parameters:

= 32,917, = 245,25, = 0,5127, = 1,1959, =0,241.

According to the results of the calculations, it follows: the deflection without taking into account the bending stiffness =0 is equal to *f* = 0.0308 м, and taking into account the bending stiffness *f* = 0.0242 м. Therefore, for short wire lengths, it is necessary to take into account the bending stiffness of the wire in the calculations of the stress-strain state.

**Output:**

1) In accordance with the studies carried out, the bending stiffness of the wires does not affect the stress-strain state of long wires of the order of 160 м.

2) For small wire lengths of the order of one meter, the bending stiffness of the wire must be taken into account.

References

1. Gimadiev R. Sh. Electric transmission line wire deformation dynamics// AIP Conference Proceedings 2027, 030002 (2018); doi: 10.1063/1.5065096, pp.1-5.
2. Gimadiev R.Sh. Power Line Deformation Dynamics / Mechanics of Solids, 2019, Vol. 54. No. 6, pp. 903-914. (<https://rdcu.be/b3doz>)
3. Ilgamov M.A. Interaction of instabilities in a hydroelastic system. PMM. Volume 80. Issue. 5, 2016, pp. 566-579.
4. Ilgamov M.A. Generalization of the Thin Plate Bending Equation under the Action of Gas. Mechanics of Solids, 2019, Vol. 54, No.2, pp. 348-355.
5. Ilgamov M.A., Mishin V.N. On the influence of the velocity of fluid movement inside the pipeline on the nature of its nonlinear oscillations// Modeling of dynamic processes in continuums. Institute of MandM KSC RU, Kazan, 1997, p. 88-95
6. Batseva N.L. Special issues of designing electric power systems and networks: a textbook // Tomsk: Publishing House of Tomsk. polytechnic un-t, 2008. 254 p.
7. Shevchenko E.V., Mitrakov V.A., Tanasoglo A.V. Determination of the reduced tension in the event of a wire break. Metal structures. 2010. V. 16. No. 3. pp. 189-198.
8. Devnin S.I. Hydroelasticity of Structures under Separated Flow. L.: Shipbuilding, 1975. 192 p.
9. Gimadiev R.Sh. Dynamics of soft shells of the parachute type. Kazan: Kazan. state energy un-t, 2006. 208 p.
10. McCombe, John; Haigh, F.R. (1966), *Overhead Line Practice* (3rd ed.), Macdonald. P. 216–219
11. Ryan, Hugh (2001), *High Voltage Engineering and Testing*, IET, p. 192, [ISBN](https://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-85296-775-6](https://en.wikipedia.org/wiki/Special:BookSources/0-85296-775-6)
12. Pansini, Anthony J. (2004), [*Power Transmission and Distribution*](https://books.google.com/books?id=hd5JncHGcLMC&pg=RA2-PA204&lpg=RA2-PA204&dq=transmission+conductor+dancing), Fairmont Press. P. 204–205, [ISBN](https://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-88173-503-5](https://en.wikipedia.org/wiki/Special:BookSources/0-88173-503-5)