Determination the conductor sag according to the period of own harmonic oscillations

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Abstract. The article substantiates the relevance of the inspection of overhead power lines by determining the mechanical loads of the conductors. The conductor sways under the action of external loads and variable internal mechanical loads. The conductor behaves in span like a pendulum. A model of the harmonic oscillations of the conductor in flight is derived to assess the mechanical loads of the conductor overhead power lines. This mathematical model is based on mathematical models of a flexible thread and a model of a physical pendulum. A conductor is a physical pendulum, where the conductor acts as the body, and in the role of the fixed axis of rotation, a straight line passing through the suspension points of the conductor. The article briefly describes an algorithm for calculating the conductor sag for the case when the conductor suspension points are at the same height. The results obtained using the developed model for calculating the sag of the conductor by its period are compared with the available experimental data. Experimental equipment is described. The error of the method is estimated.

1 Introduction

Electricity consumption in the world is projected to grow. The transmission of electrical energy from generation sources to the consumer is carried out mainly through overhead lines (OHL). The stability and reliability of power supply is determined by a number of reasons, among which the mechanical strength of the conductor of high-voltage power lines occupies an important place [1, 2]. Therefore, great attention is paid to monitoring the condition of power transmission lines.

High-voltage power lines experience horizontal and vertical static loads due to their own weight and tension of conductors and cables. Dynamic loads come out from a number of reasons: wind, icing and snow cover when temperature and air humidity change [3]. Excessive loads caused by the above reasons can lead to large elongation, overlap of conductors and short circuits, as well as breakage of overhead lines.

The mechanical loads of overhead lines are determing mainly by two methods: direct measurement using strain gauges) [4, 5, 6] or indirectly - inclinometric methods based on the values of the conductor angle of inclination using acceleration sensors - accelerometers [7, 8, 9, 10, 11].

Along with a large number of advantages, the weighing method has a number of disadvantages, namely: the need to make changes to the linear reinforcement and high cost [12]. In turn, the inclinometric method is reliable, simple and does not require changes to the design of the overhead line, but has errors in measuring the angle of inclination of the sensor (accelerometer) and errors associated with recalculating the angle of inclination due to the force of the conductor tension [7, 13].

The authors of [14] believe that the most optimal option is to build a monitoring system based on an inclinometric method that combines reliability, high accuracy in determining the angles of deflection of the sensor, as well as the ease of installing a control device with a kit of sensors on the overhead line conductor.

This article is devoted to the experimental verification of the method for assessing the load on the overhead line conductor, proposed by the authors of the work, based on the representation of the overhead line section located between adjacent supports as a physical pendulum and calculating the value of the conductor sag through the time period of its natural harmonic oscillations. The conductor sways under the influence of forces caused by wind. The inclinometric method can be used to determine the angles of deviation of the conductor in space from its equilibrium position in the swinging plane with high accuracy.

2 Brief theory of the method and measurement technique

Imagine a conductor in the span of an overhead line as an absolutely rigid monolithic isotropic structure with only one rotational degree of freedom relative to the axis passing through the suspension points (Fig. 1).

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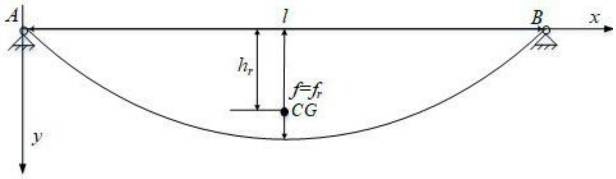

Fig. 1. Model of an overhead line conductor hanging at suspension points located at the same height, like a physical pendulum. Legend: l - horizontal distance between two adjacent suspension points (span length), m; f is the difference in heights between the highest point of suspension in the span and the lowest point of the conductor, fr is the sag of the conductor, m; hr is the distance from the center of the segment with the vertices at the points of suspension of the conductors A and B to the center of gravity (CG) of the overhead line conductor, m.

As you know, the period of oscillation of a physical pendulum is determined by the formula [15]:

$$T = 2\pi\sqrt{\frac{I}{mgh_r}}. \quad (1)$$

where g is the acceleration of gravity, hr is the distance between the center of gravity (CG) and the axis of rotation, m is the mass of the body, I is the moment of inertia about the axis around which the oscillations occur.

In the absence of a difference in the heights of the suspension on the overhead line supports, the conductor equation can be written in the following form:

$$y = \frac{1}{a}\left(\frac{l}{2}x - \frac{x^2}{2}\right), \quad (2)$$

where l is the span length, m; f - conductor sag, m; x and y are coordinates, respectively, measured along the horizontal and vertical axes. The moment of inertia is determined by integration using the formulas:

$$I = \int_0^l y^2 dm, \quad (3)$$

$$dm = qds, \quad (4)$$

here y is the vertical distance from the axis of rotation to the infinitely small section of the conductor, m; q is the linear mass of the conductor, kg.

The distance from the center of the segment with the vertices at the points of suspension of the conductor A and B to the center of gravity of the overhead line conductor along the y axis:

$$h_r = \frac{1}{m}\int_0^l ydm, \quad (5)$$

where the mass of the infinitesimal element of the conductor dm = qds; q is the linear mass of the conductor (kg); ds is the length of the infinitesimal conductor element, m.

The length of an infinitely small conductor element ds when displaced along the horizontal axis by a distance x at small sag angles θ is determined by the simplified formula [16]:

$$ds = (1 + \frac{1}{2}y'^2)dx. \quad (6)$$

where y 'is the derivative along the x-axis.

As a result of substitution of all quantities in formula (6) and simplifications, provided that $l >> f$, the expression for *f* takes the form [14]:

$$f \approx 0,31T^2 \quad (7)$$

Thus, to determine the conductor sag based on the model of natural harmonic vibrations of a conductor hanging in a span with suspension points at the same height, it is necessary to measure only the parameter T - the oscillation period, measured in seconds, and

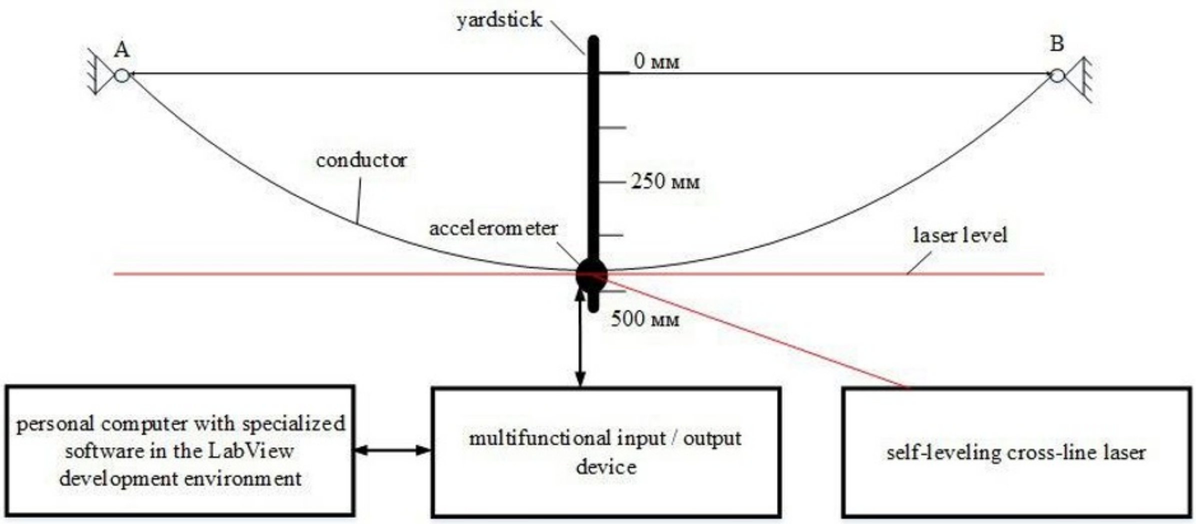

Fig. 2. Description of the experimental setup.

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calculate the conductor sag using formula (7).

3 Measurement technique for testing the developed model of natural harmonic vibrations of the conductor

To test the obtained mathematical model, an experimental setup (stand) was developed for physical modeling of conductor vibrations. The stand includes: 5.48 meters long conductor; flexible bearings at suspension points; laser level to control the height of the suspension points; screws with nuts, washers and with the aforementioned flexible bearings to adjust the height of the suspension points fixed on opposite supports and to accurately measure the conductor sag; sensor for measuring the angle of deviation of the conductor from the equilibrium position (analog accelerometer ADXL311); multifunctional input-output device FWG USB6251NI (2 channels of 16 bits for measuring two coordinates, the speed of digitization is 1000 samples / sec).

The period T is measured by counting the smallest time interval for which the conductor returns to its original extreme position in which it was at the initial moment. Deviations of the conductor from its neutral position are measured with an accelerometer.

Oscillations are given to the conductor by initially deviation it from the neutral position by a given distance. The vibrations of the conductor are then measured with an accelerometer mounted directly on the conductor. Data from the accelerometer are read through the FWG USB6251NI to a personal computer with a time error of 10-3 s (related to the speed of digitizing data from the accelerometer). Collection and processing of data occurs in software written in the LabView programming environment. The program sets the accelerometer supply voltage at startup. Then the software in a loop measures the parameters of the current signal from a two-coordinate accelerometer, while frequency and spectral analysis takes place. The software provides graphical data, tables and graphs. Opposite the center of the impromptu span, a ruler 1000 mm long is installed to measure the sag of the conductor with an error of 0.5 mm (the minimum step for measuring the length on the measuring tool - a ruler). To increase the accuracy of determining the sagging arrow, a BOSCH PCL 20 SET laser level is used, with the help of which horizontal and vertical laser beams are projected onto the wall, which allows projecting the position of the lowest point of the conductor onto a ruler at a right angle to determine the conductor sag. The description of the experimental setup is shown in Fig. 2.

4 Results and discussion

In fig. 3. a diagram is presented that compares the values of the periods of vibration of the conductor, obtained by calculation (T_{calc}) and experimental studies (T_{exp}). Data recieved on the installation described above for the case when the points of suspension of the conductor are at the same height.

The relative error in determining the oscillation period of the conductor can be determined by comparing the calculated oscillation period with the experimental value for given conductor sag in accordance with the following formula:

$$\delta_T = [(T_{\exp} - T_{calc}) / T_{\exp}] \cdot 100\% \qquad (8)$$

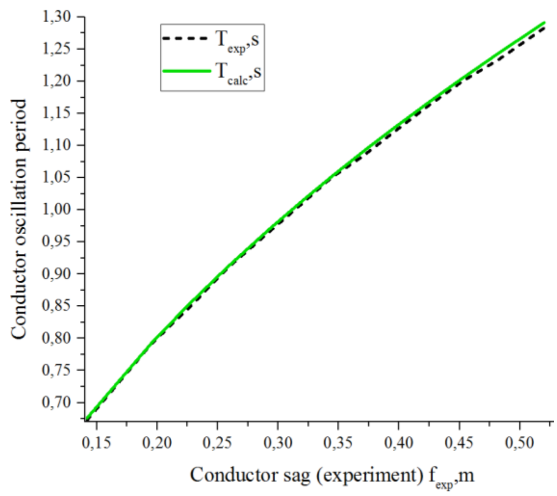

Fig. 3. Diagram of comparison of the periods of vibration of a conductor obtained by calculation (T_{calc}) and experimental studies (T_{exp}).

The results of calculating the relative error in determining the oscillation period of the conductor, obtained from the measurements of the conductor sag, in accordance with the diagram in Fig. 3, are shown in Fig. 4 by dots. The set of experimental values of the error was analyzed using the least squares method. As a result, a straight-line approximation of the dependence (line in Fig. 3) between the error in determining the oscillation period of the conductor and the boom of its sag was obtained:

$$\delta_T = 0.148 + 0.889 f \qquad (9)$$

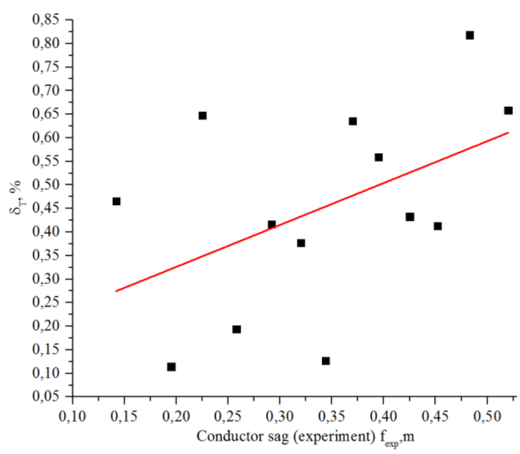

Fig. 4. The results of calculating the relative error δ_T for determining the oscillation period T of the conductor from the experimental data of the values of the conductor sag f with the construction of a linear approximation of the dependence $\delta_T(f)$.

From the diagram in Fig. 4 it follows that formula (7) gives an error in determining the oscillation period of the conductor no more than 0.85% when the sag is changed from 0.14 to 0.52 meters with a span length of 5.48 meters.

5 Conclusion

Thus, the article briefly describes a model for representing a conductor in a span between two overhead line supports, as a physical pendulum. The main elements of the physical model and mathematical expressions connecting the geometric dimensions of the conductor and its mass distributed over the span with the swing period are given. The experimental stand is briefly described, which is a physical model of the span, assembled to test the performance of the model. The results of the experimental verification of the method and statistical processing of the measurement results showed the possibility of determining the conductor sag of a conductor hanging in the span between two suspension points, according to the results of measuring the period of its swing. The error of the described method for determining the sag by the oscillation period of the conductor within the framework of the experiment was not higher than 0.85%.

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