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EXPERIMENTAL RESEARCHES OF ELASTOMERIC MATERIALS TO STABILIZE THE OSCILLATION OF POWER GRID STRUCTURES

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This paper proposes a new type of insulator, has both insulating and damping properties to improve the operational reliability of overhead power lines' structures (OHPL). In order to assess an effectiveness of the new insulator's design have made laboratory tests of a insulator model with different types of elastomer seals, differed of the rubber marks and the type of reinforcement. An experiment consist of two stages: at the first stage an object of study has been exposed to cyclical vibration, at the second – the impact of an impulsively load. Results of the research showed, that the most effective are the elastomeric gasket with a minimum rigidity characteristics without reinforcement. Using insulators with such dampers allows to reduce the first maximum impulse to a support by an average of 20% and reduce the frequency and amplitude characteristics of the system. Based on this was developed a new type of elastomer reinforcing with steel sheet elements in the form of a truncated cone.

Key words: damper, elastomeric gasket, string of insulators, lattice support, overhead transmission power line.

Introduction

The main drawback of currently used insulators is to use materials with low damping properties [1 – 4]. For this reason, usually occur weakly damped oscillations in the rod of the insulator under the influence of external excitation forces [5 – 7]. This paper presents the experimental research into the use of elastomeric materials to stabilize the power grid structures.

Based on the theoretical research was proposed the design of damper device shown in fig. 1. The distinguishing feature of this design is that the damping assembly which consists of two delta-shaped staples, perceive tensile load, causes in the gasket of elastomer compression deformation. Thus, it is possible to use flexible elastomeric damper, suspension and conductor-stayed systems. On the power lines such element can be mounted into the polymer insulator strings, the more that the elastomeric gasket is a good dielectric [8, 9].

1. Design of the damper device

The new type of insulator proposed in this paper (fig. 2) having an insulating and damping properties simultaneously and can be used to improve the operational reliability of overhead lines owned by the enterprises of electrical networks.

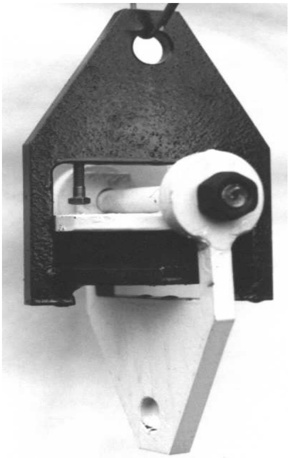


Fig. 1. The damper's general view

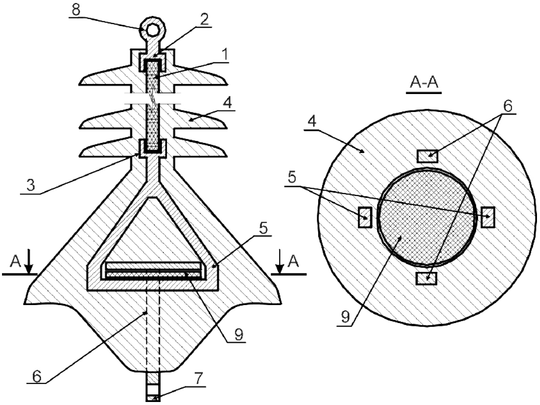


Fig. 2. The insulator with the damper

The insulator, showed in fig. 2, consists of FRP rod 1 and fixed at its ends of metal end fittings 2, 3 with connecting elements 7, 8, which are covered with a protective sheath 4 of a dielectric polymer material. Between the lower end fitting 3 and the element 7 inserted damping assembly in the form of two delta-shaped staples 5, 6 are connected in series with a gasket disposed therebetween elastomeric material 9 is of a cylindrical form.

2. The methodology of experimental researches

In order to assess the effectiveness of the above designs were conducted laboratory tests of model insulator strings, which were introduced damping assembly.

During the experiment used elastomeric gasket provided by Ukrainian Research, Design and Technology Institute of elastomeric materials and products (URDTI «DINTEM»), Dnepropetrovsk city [10].

The main purpose of the tests was to determine the effectiveness of the proposed design under dynamic loads and impacts to the OHPL supports from the electrical cabels and ground wires and an evaluation the structural damping, depending on the type and design of the elastomeric gasket.

So elastomeric materials have a pronounced nonlinear properties, and the data about physical and mechanical properties are clearly insufficient to carry out theoretical studies, it was decided to establish a simple methodology to assess the complexity with minimal vibration damping properties of elastomeric materials in the proposed design.

According to the proposed methodology were tested insulator strings with different types of elastomer gaskets, rubber marks, and differing types of reinforcement. The experiment consisted of two stages. At the first – stage research object exposed to cyclical vibration load, at the second – to impulsively load. Tests were conducted in December 2014 in the Testing Center of Donbass National Academy of Civil Engineering and Architecture at a temperature of +1^{0}C.

2.1. Tests of the insulator strings with damping unit on the action of the cyclic vibration load

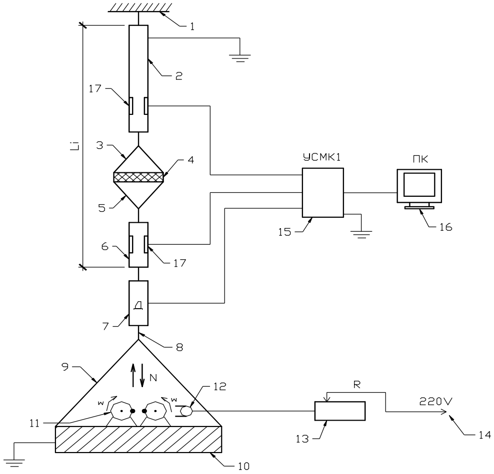


Fig. 3. The scheme of insulators strings' tests under cyclic load:
1 – a support;
2, 6 – a model of a string;
3, 5 – the damper;
4 – the elastomeric gasket;
7 – a dinamometr;
8 – a wire;
9 – a metal frame;
10 – a weight load;
11 – the vibrator;
12 – the DC motor;
13 – a strenght;
14 – the power supply;
15 – a monitoring system;
16 – PC;
17 – strain gauges

The insulator was modeled using a steel pipe with a diameter of 22 *mm*, which was introduced on hinges damping assembly. The total length of the string was 1.5 *m*. Strings of similar length are used on real lines with voltage of 110 k*V*.

The testing scheme of insulator strings by the cyclical load is shown in fig. 3.

Prior to the tests, was a preliminary calibration of strain gauges readings (in cross-section has 6 strain gauges), located in the stringd between the damper and the wire, between the damper and the support by comparing the readings with the latest readings of the dynamometer by-step application of the load unit weight loads.

To the suspended insulator strings through the conductor sent the load form the weight load , on which was established vibrator, with the help of which excited oscillates system (fig. 4).

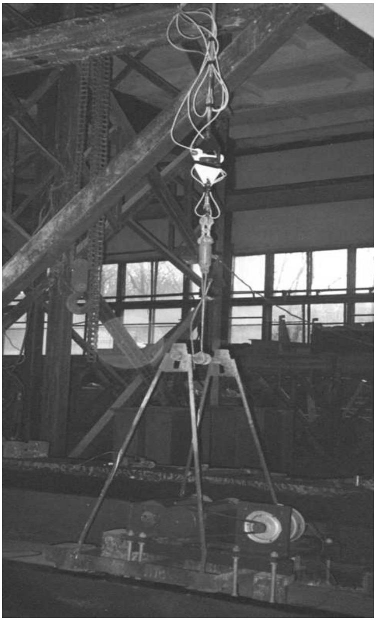
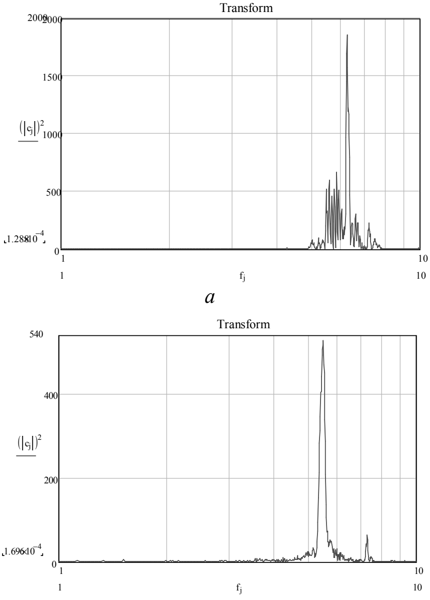


Fig. 4. The test model’s general view



a

b

Fig. 5. Spectral dependences: *a – the model without elastomeric gasket; b – with gasket*

Controlled parameters were voltage in insulator strings between the damper and the wire and between the damper and the support, measured by the strain gauges of resistance and also the force in the connecting conductor, measured with a dynamometer. Variable parameters were the mass of the weight load load and the frequency of exposure.

In order to assess natural frequencies of structural vibrations were built spectras using a Fast Fourier Transform (FFT). As seen in fig. 5 the use of elastomeric gasket reduces the first natural frequency of the system from 6.2 to 5.5 *Hz*. Thus, when applying the described damper may apply so-called "frequency tuning."

In fig. 6 can see the characteristic recording of the signal implementation by the time. The values of the vertical axis corresponds to the voltage in kgf / cm^2, the line voltage shown in the body of between damper and–strings between the wire and damper broken lines support.

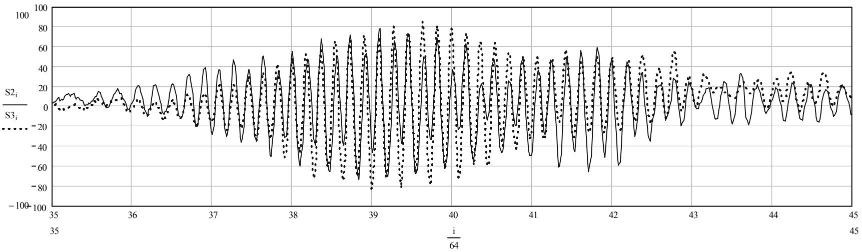


Fig. 6. An example of the signal realization

2.2. Tests of the insulator strings with damping unit on the pulse loading at breakage of wires

To study the damping properties of the proposed insulator have been conducted researches of the dynamic behavior under the influence of the impulse loading from the wire breakage. As the object of study was used the span model of wire between the anchor and intermediate supports. The case of wire breakage was simulated in the second span fromthe anchor support. The experimental scheme is shown in fig. 7.

The wire was modeled using a steel conductor with a diameter of 10 *mm* (fig. 8) with equivalent stiffness properties. The span length is 30 *m*. To create a design load the span of electrical conductor were pre-loading using the unit weight loads by mass 10 *kg*, is rigidly attached to the wire.

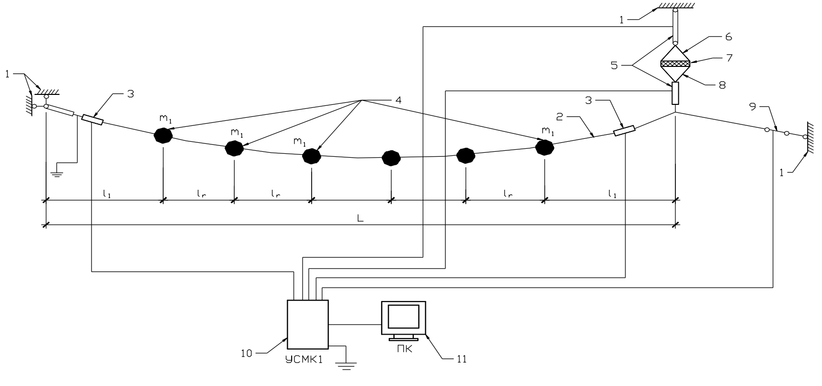


Fig. 7. Driving test insulator strings cyclical load: *1 – a support; 2 – wire; 3 – dynamometers; 4 – loads; 5 – model garlands; 6, 8 – damper; 7 – elastomeric gasket; 9 – breaking bracket; 10 – monitoring system; 11 – PC*

Breakage was carried out using a discontinuous brackets. During the breakage were measured: the moment of the conductor's breakage, a traction in the wire near the insulator, a strenght in the insulator rod between the damper and the support and between the damper and the conductor is carried out using the monitoring system of building structures "UMSK-1." The frequency of the parameters removal was 64 *Hz*.

The open architecture of the "USMK-1" enabled mobile make and implement the breakage sensor, the principle of action is based on breaking the electrical circuit [11–13]. During the experiment achieved tension in the conductor from 1000 to 9000*N*, with a step of 100*N*.

Fig. 8. The insulator string’s general view

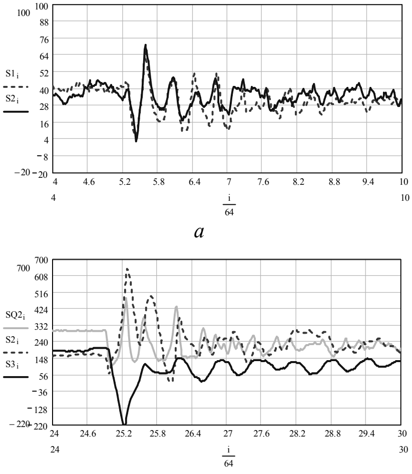
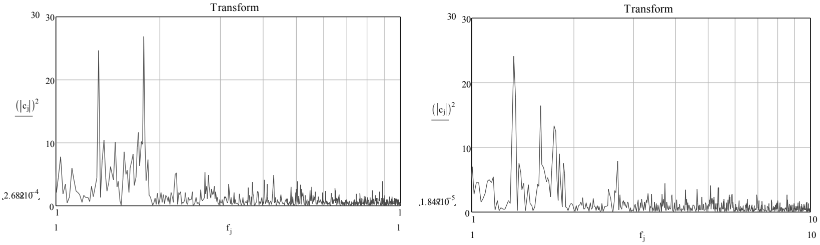


Fig. 9. Change forces in the insulator's rod: *a – without estameric gaskets; b – with elastomeric gasket*

Fig. 9,*a* shows the change of forces for the insulator without elastomeric gasket (S1 – forces in the rod between the damper and the conductor, S2 – forces in the rod between the damper and the support). Fig. 9,*b* shows forces in the insulator with the gasket without reinforcing (SQ2 – the traction of in the conductor, S2 – forces in the rod between the damper and the support, S1 – forces in the rod between the damper and the conductor).

Although the use of FFT (fig. 10) allows to judge about the frequency shift of the system with the introduction one or other damper, but to evaluate the vibration damping properties by the frequencies is difficult [14, 15].

The most complete information about the oscillations damping by the elastomeric element on frequencies can be obtained on the basis of the filtering the digital signal implementation obtained by using Haar transformation [16, 17, 18]. With its help, in fact, carried out a multi-stage digital filtering the signal through a set of filters, low and high frequency with constant relative transmittance [19].



a *b*

Fig. 10. The spectra: *a – without estameric gaskets; b – with elastomeric gaske.*

The construction of discrete Haar transformation begins from the determinaion of the scaling function $\varphi(u)$, depending on the of some restrictions and is used to specify the "mother" function $\psi(u)$. The basis functions, which representing the signal, defined by extensions $\psi(u)$. The form of "mother" transformation is not unique and depends on the desired order of the transformation. The analyzed signal must consist of 2^M samples, where M – whole number. During the the conversion the signal is decomposed into M+1 levels (i=1,0,1, ..., M+1). Each i-th level consists of $k = 2^i$ partially overlapping basis functions are equally distributed in the interval $2^M/k$. The realization of the signal is uniquely determined by the expression:

$$x(t) = A_V + \sum_{j=1}^{N} \sum_{k=0}^{2^{j-1}} \psi(2^j \cdot t - k \cdot T),\ 0 \le x(t) \le T, \tag{1}$$

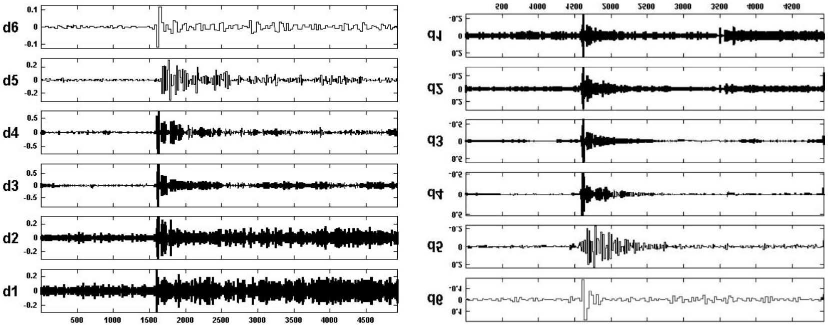
where $\psi(2^i \cdot t - k \cdot T)$ – Haar functions, t - time.

Through the ratio given the function algorithm of normalized low-frequency and high-frequency digital filters. Setting the value of “M” practically determines the "Tree" of digital signal filtering. As a result of the decomposition of the signal is a set of implementations that display the time dependence of the filtered frequency bands in normalized components of the original signal. In this frequency band f_i for each implementation associated with the sampling frequency and the signal $f_в$ may be determined as follows:

$$f_i \in \left[\frac{f_в}{2^{i+1}}; \frac{f_в}{2^i} \right]. \tag{2}$$

Thus, the use of Haar transform allows you to explore a broadband signal, detailing it in the normalized frequency bands. Thus it is possible to identify the characteristics of the signal hidden in its initial implementation. Filtered implementation can be further analyzed by conventional means of statistical processing of signals.

The highest frequency in the transformation is determined using the Kotel'nikov theorem. So, the sampling frequency signal is 64 *Hz*, the lower frequency will be 32 *Hz*. Fig. 11 graphs $\tilde{d}1$-$d6$ correspond to octave band signals expansion $f \in [0,5; 32]$ *Hz*.



a *b*

Fig. 11. Discrete Haar transformation: *a – the signal between the damper and conductor; b – the signal between the damper and support*

From the analysis of the results can be concluded increasing of dissipative properties of the elastomeric gasket with increasing frequency the disturbing force. To quantify this fact was introduced stabilization factor, which is the ratio of the amplitude of the system oscillation before the damper (A_2), and after the damper (A_1):

$$Y_n = \frac{A_2}{A_1}. \tag{3}$$

Analysis of the results allowed to reveal the dependence of attenuation coefficient on the frequency (fig. 12) and the magnitude of the pre-compression damping (fig. 13).

The graph on fig. 12 is built on the tests´basis of the insulator strings by cyclical load:

$$Y_n = \left(\frac{\sum_{1}^{n} M_2 \cdot \frac{1}{n} - S_2}{\sum_{1}^{n} M_1 \cdot \frac{1}{n} - S_1} \right), \tag{4}$$

where n – the number of oscillation′s periods in the implementation of the selected target frequency oscillations; $M_{2,1}$ – the maximum of realization for the period before and after the damper respectively; $S_{2,1}$ – the average value of the selected implement, before and after the damper.

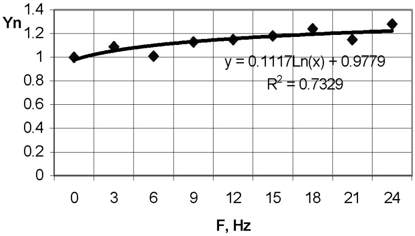


Fig. 12. Dependence of the stabilization of the frequency of the disturbing force

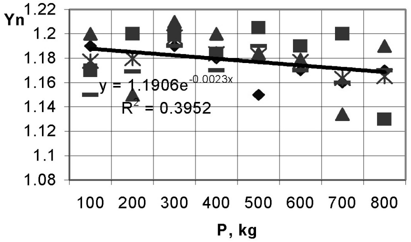
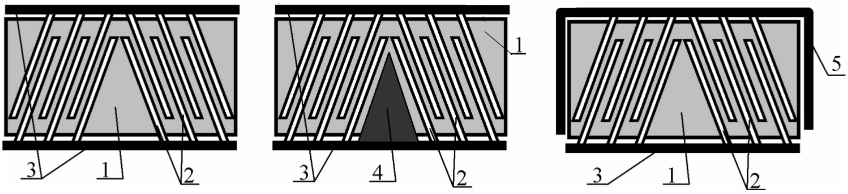


Fig. 13. Dependence of the stabilization of the value of the compressive force

The graphs in fig. 12 and 13 show an increase of the vibration damping properties of elastomers with increased frequency and decrease the amount of compressive force. However, if the dependence of the frequencies managed to build quite precisely, to establish Yn depending on the compression force to simulate a real forces arising from the conductor breakage of overhead lines of 220 k*V* and above, it was not possible, because the conductor′s tension of data overhead lines up to several tons .

3. The proposed reinforcement type of elastomeric parts

As an alternative, we propose a new type of reinforcement of elastomeric parts. A feature of this type is the reinforcement of the elastomer by the sheet steel elements in the form of a truncated cone. In fig. 14,a is shown rubber reinforced supporting part (RRSP) with conical reinforcement; in fig. 14,b a lower support plate rigidly attached the locking element in the form of a cone; in fig. 14,c RRSP enclosed in a steel beaker. The reinforcing elements are derived from pairwise elastomeric body and fixed to the lower and upper support plates.



a *b* *c*

Fig. 14. The proposed types of the reinforcement of RRSP: *1 – elastomeric material, 2 – cone steel sheets, 3 – support plates, 4 – the locking element in the form of a cone , 5 – steel beaker*

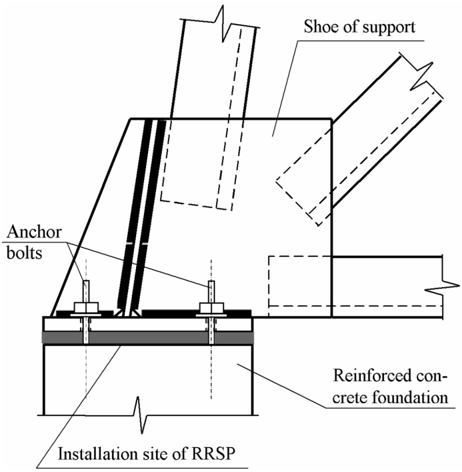


Fig. 15. The support assembly

In the proposed RRSP is possible application of the most soft elastomers. The conical reinforcement facilitates the fullest use of the height of the elastomer material, and the use of the steel beaker, in this case, promotes deformation of the elastomer along the line of action of force, which also contributes to more efficient damping.

To reduce the dynamic impacts in the area of lattice towers′bases of overhead lines proposed to establish new types of RRSP under steel plates of the support′s bases (fig. 15). The use of dampers in this case will not only damping of oscillations in the base area, but also allow you to change and adjust the natural frequencies of the tower supports, ie to apply the so-called frequency detuning.

4. Conclusions

1. Analysis of test results showed a fairly clear dependence of the dissipative properties increase of the system while reducing the stiffness parameters of elastomeric seals. This served as the basis for developing a new type of the steel sheetreinforcement of elastomer elements in the form of a truncated cone.

2. The experimental results showed that the most effective are the elastomeric gasket with a minimum rigidity characteristics (a hardness by Shore is 40) without reinforcement. Using insulators with such dampers allows to reduce the first maximum impuls to the support by an average of 20% and to reduce the frequency and amplitude characteristics of the system.

3. During the processing of the experimental data was set ineffectiveness of horizontal reinforcement of RRSP, because stabilizing effect observed in the range of 3% and is comparable to the experimental error.

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ЭЛАСТОМЕРНЫХ МАТЕРИАЛОВ ДЛЯ СТАБИЛИЗАЦИИ КОЛЕБАНИЙ ЭЛЕКТРОСЕТЕВЫХ КОНСТРУКЦИЙ

В статье предложен новый тип изолятора, обладающий одновременно изолирующими и демпфирующими свойствами для повышения эксплуатационной надежности конструкций воздушных линий (ВЛ). Для оценки эффективности применения новой конструкции изолятора выполнены лабораторные испытания модели изолятора с различными типами эластомерных прокладок, отличающихся маркой резины и типом армирования. Эксперимент состоял из двух этапов: на первом этапе объект исследования подвергался воздействию циклической вибрационной нагрузки, на втором – действию импульсивной нагрузки. Результаты исследований показали, что наиболее эффективными являются эластометные прокладки с минимальными жесткосными характеристиками без армирования. Использование изоляторов с подобными демпферами позволяет уменьшить первый максимальный импульс на опору в среднем на 20% и снизить частотные и амплитудные характеристики системы. На основании этого разработан новый тип армирования эластомера стальными листовыми элементами в форме усеченного конуса.

Ключевые слова: демпфер, эластомерная прокладка, гирлянда изоляторов, решетчатая опора, воздушная линия электропередачи.

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ЕЛАСТОМІРНИХ МАТЕРІАЛІВ ДЛЯ СТАБІЛІЗАЦІЇ КОЛИВАНЬ ЕЛЕКТРОМЕРЕЖЕВИХ КОНСТРУКЦІЙ

У статті запропоновано новий тип ізолятора, що має одночасно ізолюючі та демпфіруючі властивості для підвищення експлуатаційної надійності конструкцій повітряних ліній (ПЛ). Для оцінки ефективності застосування нової конструкції ізолятора виконані лабораторні випробування моделі ізолятора з різними типами еластомірних прокладок, що відрізняються маркою та типом армування. Експеримент складався із двох етапів: на першому етапі об'єкт дослідження піддавався впливу циклічного вібраційного навантаження, на другому – дії імпульсивного навантаження. Результати досліджень показали, що найбільш ефективними є еластомірні прокладки з мінімальними жорсткісними характеристиками без армування. Використання ізоляторів з подібними демпферами дозволяє зменшити перший максимальний імпульс на опору в середньому на 20% і знизити частотні та амплітудні характеристики системи. На підставі цього розроблений новий тип армування еластоміру сталевими листовими елементами у формі усіченого конуса.

Ключові слова: демпфер, еластомірна прокладка, гірлянда ізоляторів, ґратчаста опора, повітряна лінія електропередачі.

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A new type of insulator, has both insulating and damping properties to improve the operational reliability of overhead power lines' structures (OHPL) is described. A new type of elastomer reinforcing with steel sheet elements in the form of a truncated cone was developed.
Table 0. Fig. 15. Ref. 19

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