Optimization of external power delivering system of object by mechanical influence on the work of power line wires

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Abstract

Introduction. The work is devoted to the research of methods of decreasing the sag of the power lines wires using thermo-compensating devices. In this work will be reviewed types and structure of active thermal compensating devices.

Research and methods. Mathematical models that characterize the work of power line wires were used.

Results and discussion. Proven, that compensation of power line wires sag by using active thermal compensation devices, that are made of alloy with “shape memory effect” (SMA) creates conditions under which it is possible either to increase spans, or to reduce the height of the transmission towers, while preserving the existing estimated spans.

In the industrial applications, it is necessary not only to calculate the mechanical response of the actuator in terms of recovery force or deformation, but also to evaluate its temporal characteristics, i.e., the actuation and reset times.

Compensation devices in the most general form are elements of force action mechanically connected with wires and they have a force influence on wires.

The advantage of active thermal compensation devices of power line arc of sagging over existing inventions was shown.

Conclusions. Scientific novelty of this work consists in research of influence of active thermal compensation devices on work of overhead power line wire.

Introduction

An analysis of structural costs for the construction of power lines shows that the cost of installation and assembling them is 20–35% and the remaining 80–65% are spent on towers, towers bases, insulation, grounding [1]. Therefore, one of the promising directions for solving the problem is compensation of the temperature sagging of wires and wire ropes of overhead power lines, which allows to increase spans without changing the height of the hanging wire[6].

It is known that the main limitation in choosing the maximum spans is the permissible approach distance of the wires to the ground or to the engineering structure which is intersected. Spans are determined for the case of maximum ambient temperatures. The permissible approach distance of the wires should be less than the difference between the height of the suspension of the lower wires of the power lines and their extreme sagging in the span. With existing fastening of wires on towers, there is a reverse dependence [3] between temperature extension and tension in wires. It follows that in the presence of devices that increase the tension in the wires at maximum temperatures, the compensation of the temperature sagging of power lines wires is realized. Compensation of power line sag creates conditions under which it is possible either to increase spans, or to reduce the height of the transmission towers, while preserving the existing estimated spans. As a result, the specific consumption of the towers, linear fittings, insulation is reduced, and the time for construction of the power lines is reduced also [6].

Materials and methods

It should be noted that the main function of such methods and devices is to reduce tension in the wires of power lines in the event of an overload (hoarfrost) for the purpose of preventing wires from breaking, reducing the probability of crossing the wires in strong winds, fighting hoarfrost, fighting vibration of wires [9].

Shape memory alloys (SMA), because of their unique mechanical characteristics and shape memory effect (SME), have been widely used as force and displacement actuators in many fields. In the industrial applications, it is necessary not only to calculate the mechanical response of the actuator in terms of recovery force or deformation, but also to evaluate its temporal characteristics, i.e., the actuation and reset times [9].

Compensation devices in the most general form are elements of force action mechanically connected with wires and they have a force influence [7] on wires. However, to some extent compensation of the temperature arc of sagging can also be achieved by optimizing the location of towers and wires on towers.

Ways of wires sag compensation can be divided by the duration of influence to the wire on power line: continuous; periodic; one-time impact.

By the nature of the working element, the compensation devices can be divided into: load type, spring type (with compression springs, stretching springs); hydropneumatic; jumper compensators; combined [6].

By the way of connecting a working element with a power line wire, the compensation devices can be divided into those that have a connection to the power line through the insulating element and those that have a direct connection to the conductor. This paper presents the fundamental characteristics of SMA and a complete design mathematical model of an active thermal compensator. It is shown, that compensation devices can react not only to tension in the wire, but also to the temperature of the conductors of the power lines (Patent of Ukraine for invention № 92091, H01R 11/00. – Patent of Ukraine № 10389, F 03G 7/06. Termopryvod/ Shesterenko V. Ye., Shesterenko O. V., Patent of Ukraine №14520, H01H 33/70).

Results and discussion

The purpose of this work is the development and research of multifunctional devices for compensating temperature arcs of sagging of power lines wires, optimization of their parameters, research of combined work of wires in spans with similar devices. The results of these studies can be applied to power lines of any voltage ratings [4].

The calculation and operation of such nodes of the directed load, which are the stretching and compression springs, are well studied. When reducing the tension in the wire, the spring is pulling the wire by reducing its length. With increasing tension in the wire, the spring increases [6]. This automatically adjusts the tension in the wire and the sag. This is how the node of the directed load which is located parallel to the wire of power line is functioning.

The analysis shows that, as a rule, for all the wires in the the estimated span is determined by the sagging of the wire (arc of sagging) at maximum temperatures.

When using identical transmission towers, the specific cost of construction of a power line depends on the number of towers per 1 km of the length of the line []. On the other hand, an increase in spans without replacement of wires is possible only to a certain magnitude, which can be increased by using the new designs of towers. Increasing the height of the towers causes disproportionate using of materials (metal, reinforced concrete, wood, etc.), which leads to an increase in specific value.

Given the fact that there is a reverse dependence between the temperature extension of the wires and the tension in the wires, compensation of the temperature arcs of sagging of the wires can be accomplished by increasing the tension in the wires at the maximum temperature.

At the same time, without breaking the restrictions, you can reduce the sag of wires, which allows either to increase the span, or to lower the height of the towers with existing spans [5].

Load type compensators are widely used in electric transport power lines. Because of them it is possible to minimize the arc of sagging of the contact wire [2].

The spring and hydropneumatic thermo-compensators are nodes of directed loads, which are mechanically connected to the power line wire.

Mechanical properties of nitinol. The thermal compensation of the arcs of sagging is implemented by the elements of force action, which are fastened to the wire and affect on it. Due to the fact that the material with a “shape memory effect” has a significant impact strength, a high endurance limit, easy to bend, dampens vibration, does not corrode even in seawater, does not oxidize when heated to a temperature of 880°K, does not crack under stress and is non-magnetic [1], from this material it is possible to make a power element in the form of a thread in the length of 1–8 m and to set it parallel to the segment of the wire in each span.

When the air temperature increases, the length of the wire increases. When the ambient temperature reaches the temperature of the start of the reverse martensitic transformation of the thermal compensator, it begins to pull the wire by changing its own length. With further increase in temperature, the wire continues to increase its length, and the thermal compensator – to decrease [6].

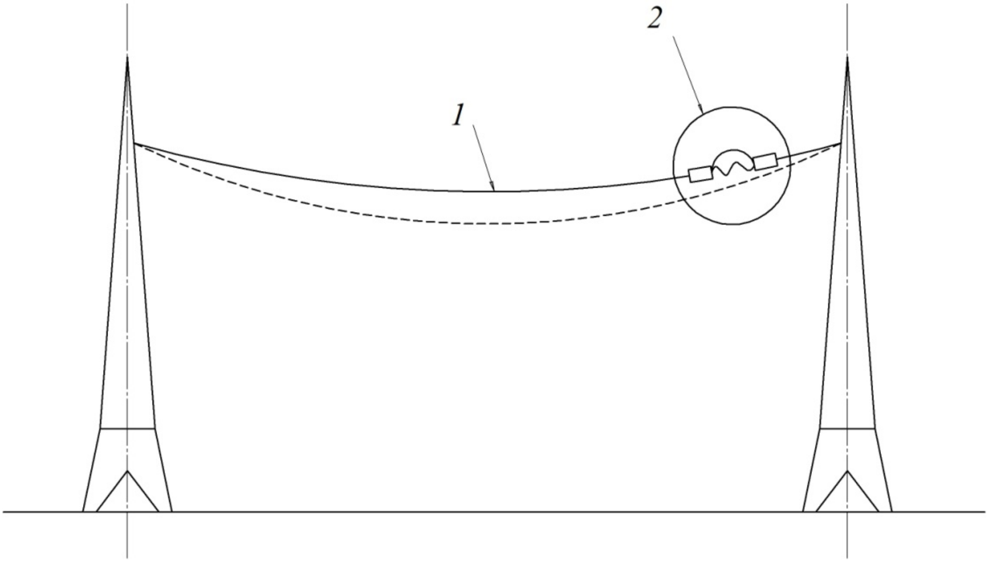

Figure 1. Principle of implementation of thermal compensation of wire sag on overhead power line

Using the unique properties of a material with a “shape memory effect”, it is possible to have a zero or negative extension of the power line wire while temperature increases.

Figure1 schematically shows the span of the overhead power line with the thermal compensator that is made from the material with “shape memory effect”.

Wire 1, secured in the span on the towers, has a temperature compensation unit 2 which consists of a thermosensitive element.

Work of thermal compensator on power line

The thermosensitive element at maximum temperature is compressed, the tension in the wire 1 increases and the sagging arc decreases (solid line of Figure1) in comparison to the arc without compensation (dashed line). If the temperature of the wire drops below the martensitic point (about 288°K), the thermosensitive element loses its rigidity and under the action of stretching aligns along the wire. With the next increase in temperature, the thermal compensator restores its shape.

The main requirement for the operation of the thermal compensator with “shape memory effect” is: the length of the section of the wire, parallel to which the thermal compensator attaches, shall be equal to the length of the thermal compensator in the unloaded state, increased by the magnitude of the maximum permissible deformation of the compensator in the area parallel to the wire, and the value of the maximum possible deformation of the thermal compensator shall be equal to the absolute elongation of the wire in the given temperature range [8].

The thermal compensator can connect two spans of the wire. The force which it perceives, is limited only by the horizontal component of tension in the wire, which allows to significantly reduce the cost of materials on the thermal compensator. In addition, such fastening of thermal compensator thanks to the flexible coupling of two adjacent spans of the wire, gives an opportunity to regulate the vibration of the wires. In this case, the energy of the fluctuation of a wire in one span is transmitted to adjacent spans and summed there with the energy of oscillations of these spans. Since the energy transfer is carried out through a flexible compensator, the amplitude, frequency and phase of the oscillations change, and the summation of such oscillations leads to their weakening. Thus, the damping effect of the thermal compensators is similar to the action of vibration dampers [7].

Making wires or springs with zero or negative temperature extensions for a certain temperature range has become possible after the discovery of the unique property of some alloys to “memorize the shape” [6]. Most clearly this property is expressed in the alloy of nickel with titanium – nitinol. The alloy is heated to transition to a high-temperature modification and in this state it is given a certain shape. Then the alloy is transfered to another, low temperature phase. This phenomenon reminds the thermoelastic transformation. If after this the product from the alloy in the martensitic state is subjected to repeated plastic deformation and then heated back to the high-temperature modification, it will receive its original form, which was given to it at the first deformation in the state of high-temperature modification [1] due to the reverse martensitic transformation.

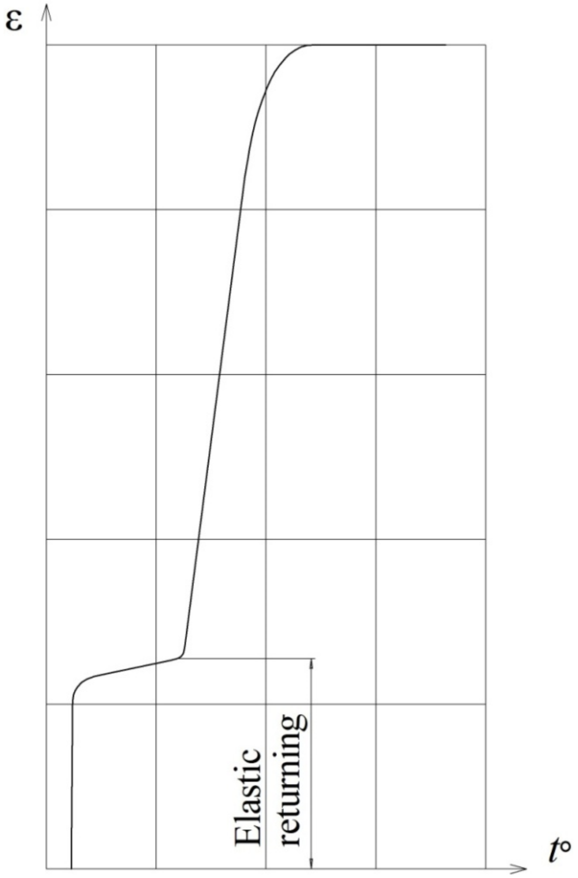

Figure 2. Stages of shape memory alloy returning to its original form

In order to reduce the arc of sagging of the wires at maximum temperatures and increase the estimated span in the overhead power line, which contains wires, fixed in the spans, at least part of the wire is made using a material with "shape memory effect".

Characteristic of the deformations of the thermal compensator that is made from the material with "shape memory effect" are shown in Figure2. The temperature of the start and end of the martensitic transformation, respectively $M_s \approx 282^\circ K$, $M_f \approx 278^\circ K$ and the start and end of the reverse martensitic transform, respectively $A_s \approx 285^\circ K$, $A_f \approx 306^\circ K$. The shape of the curve of dependence $\Delta l_к = f(t)$ is determined by the rate of heating and cooling.

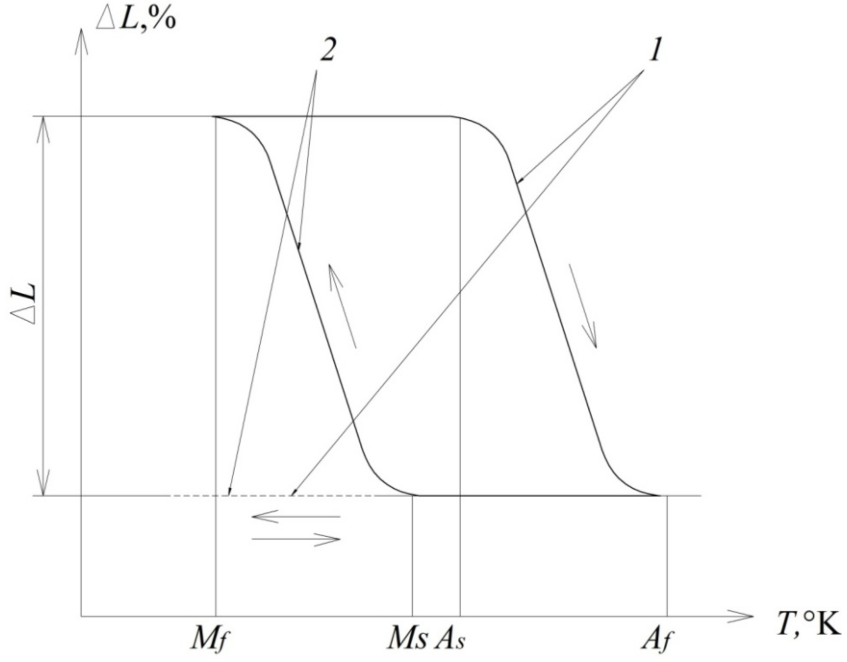

Figure 3. Dependence of deformation of an element with "shape memory effect" from its temperature:
1 – reverse transformation; 2 – direct transformation.

Hysteresis of shape memory alloys. On the magnitude of the hysteresis affects the composition of the material with "shape memory effect". Thermal compensator activation temperature depends on the load, i.e. working points of the same material are not stable and can move a few degrees [7].

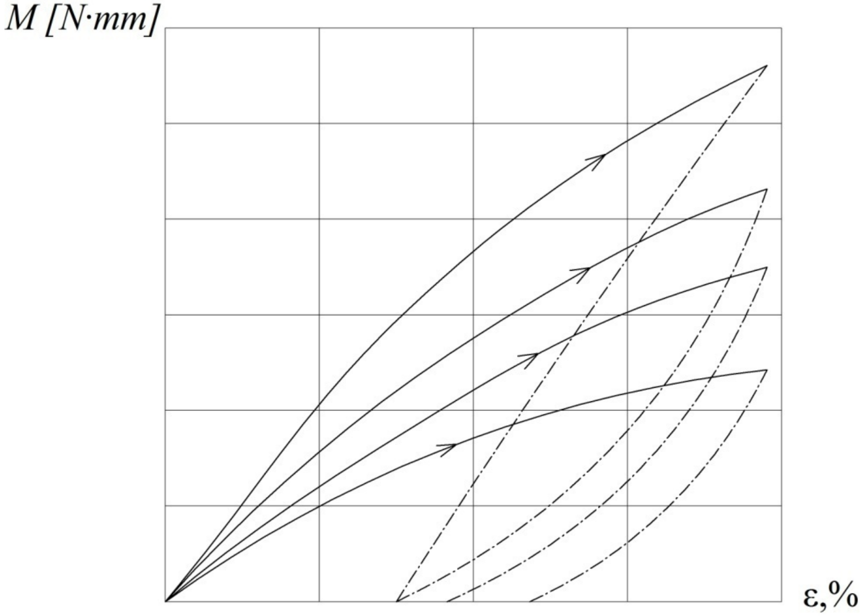

Figure 4. Dependence of deformation from applied load

When examining the joint operation of the wire and the thermal compensator, made of material with “shape memory effect”, we will take into account the piecewise-linear approximation of the performance characteristics of the thermal compensator.

At the point A_f the thermal compensator completely restores its shape. The position of the wire with the thermal compensator is indicated by a solid line in Figure1.

With a decrease in temperature, the thermal compensator, due to the presence of hysteresis, continues to keep its shape (A_f-M_s).

Lowering the temperature to the start of a direct martensitic transformation (point M_s) causes deformation of the thermal compensator. Tension in the wire in the temperature range from the direct martensitic transformation (point M_s) to its end (point M_f) varies along the curve M_s – M_f. With further lowering of the temperature, the thermal compensator did not participate in the work of the wire, and the tension changes according to the natural characteristic.

In electrical grids, the dependence of the stresses in the wire that came from the load and the temperature is expressed by the equation of the state of the wire.

Analysis of mathematical models that characterize work of a wire with thermal compensator

Because of the fact that the characteristics of the thermal compensator are unambiguous, several equations are required to describe the operation of the wire with the thermo-compensator.

For a section of a characteristic of a material with “shape memory effect” $M_f \le t \le A_s$, where the thermal compensator does not significantly affect on the work of the wire, the equation of the state of the wire does not differ from the equation without the thermal compensator:

$$\sigma - \frac{v^2 \cdot E \cdot l^2}{24 \cdot \sigma^2} = \sigma - \frac{v^2 \cdot E \cdot l^2}{24 \cdot \sigma_0^2} - \alpha \cdot E \cdot (t - t_0),$$

where v_0 – the specific load of the wire in its initial state;

t_0 – the temperature in the initial state;

σ_0 – tension at the lower point in the initial state;

E – modulus of elasticity;

α – temperature coefficient of linear elongation of the wire material;

l – the length of the span;

v,σ,t – Specific load, tension, and temperature in the final state.

At the section of the characteristic $A_s \le t \le A_f$ (Figure3) the thermal compensator activates and restores its shape.

The magnitude of the direct and reverse action of the shape memory alloy elements depends on the load (Figure 4).

This increases the tension in the wire and decreases the arc of sagging. Mathematical model of the state of the wire for the given range:

$$\sigma - \frac{v^2 \cdot E \cdot l^2}{24 \cdot \sigma^2} = \sigma_0 - \frac{v_0^2 \cdot E \cdot l^2}{24 \cdot \sigma_0^2} - \alpha \cdot E \cdot (t - t_0) - \frac{l_k \cdot \alpha_k \cdot E}{l} \cdot (t - A_s),$$

where α_k – temperature coefficient of elongation of the thermal compensator.

$$\alpha_k = \frac{\varepsilon}{100 \cdot \Delta t_{ф}},$$

where ε – maximal elongation (compression) of the material with “shape memory effect”, %;

$\Delta t_{ф}$- temperature range of phase transformation.

Conclusions

1. Results of research data can be applied for power lines of any voltage ratings, with any transmission towers.
2. A material with “shape memory effect” can be used to optimize the power lines.
3. One of the promising directions for solving the problem of optimization of power lines is compensation of temperature sagging of overhead power line wires, which allows to increase spans without changing the height of the suspension of the wire.

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