Power Line Pylon for Installation in Heaving Permafrost Soil

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Abstract. Based on analysis of known patent and scientific and technical information, new design of power line pylon has been developed, intended for installation in heaving permafrost soils. Cryophobic antifriction coating is applied to pylon surface located in active layer of soil to reduce intensity of pylon upfreezing from soil. It is proposed to place mechanical devices that increase adhesion to frozen soil below the zone of maximum summer thawing. The possibility of using polyurethane as cryophobic coating is considered. Studies have been carried out to maintain adhesion of coating to concrete surface in process of atmospheric exposure for two years.

1. Introduction
The practice of operating power lines in climatic conditions of Yakutia shows that significant increase in intensity of upfreezing of pylons from the ground is due to climate warming and increase in thawing depth in summer. This circumstance determines the need for development of special structures that provide possibility of effectively reducing shear stresses arising from frost heaving of soil, as well as vertical displacements of pylon foundations.

2. Actuality
Pylons for power transmission lines are one of the main structural elements of systems for distribution of electrical energy between power generation facilities and electricity consumers. Usually, main materials for pylon manufacture are wood, reinforced concrete, steel, and fiberglass.

Shear stresses of frost heaving act on pylons in the underground part when installing pylons in permafrost soils. Gradually, during operation, vertical displacements (upfreezing) reduce deepening of pylons into the ground, which is one of the most common causes of emergencies.

Intensity of pylon upfreezing, observed in autumn – winter period during soil freezing, is mainly determined by two factors – moisture content of soil and thickness of seasonal soil thawing. Freezing of moistened soil, which begins from the surface, is accompanied by increase in its volume, explained by increase in volume of ice when water freezes. When soil thawed during the summer season freezes, underground part of pylon is annually subjected to vertical movements. The amount of annual upfreezing depends on moisture content of soil and thickness of seasonal thaw layer. If depth of pylon does not exceed thickness of active layer in waterlogged soils, vertical annual displacements can reach 8-9% of foundation depth.

The main way to avoid upfreezing of pylons from the ground is to deepen them below the maximum level of depth of seasonal thawing. Part of the pylon foundation, located in layer of
permafrost soil, freezes into it and resists upfreezing. However, with insufficient deepening of pylons, adhesion forces of pylon surface with frozen soil may not be enough and process of upfreezing begins. The climate warming observed in recent years, especially intense in Arctic regions, will contribute to increase in thickness of soil thawing and its moistening. The risk of increasing number of emergencies associated with frost upfreezing of power transmission line pylons from the ground can significantly rise.

3. Problem definition
It is necessary to develop special technical solutions to reduce intensity of upfreezing of power transmission line pylons from permafrost soil. These solutions, on the one hand, reduce shear stresses during volumetric deformations of soils during freezing of active layer and increase adhesion to frozen soil below seasonal thawing boundary on the other hand.

4. Theoretical and experimental research
The analysis of design features, as well as proposed technical and technological solutions, carried out on the basis of patent and scientific and technical information, in addition to aforementioned expediency of deepening pylons into layer of permafrost below the maximum depth of seasonal thawing, shows possibility of using following approaches:
- treatment or impact on soil in active layer around the base of the pylon, which reduces friction and freezing of its surface to the ground;
- treatment of the pylon base surface, which reduces friction and freezing to the ground in active layer and increases these characteristics below seasonal thawing zone;
- usage of mechanical methods of adhesion of pylon foundation in layer of permafrost soil.

First approach is illustrated in, for example, patents [1, 2], in which, in order to reduce intensity of pylon upfreezing, it is proposed to fill the space between base and pit walls with pieces of frozen water-saturated soil during installation, after which the upper part of space is thawed with steam or hot water until the level of water-saturated soil mass formed over pieces of frozen soil during thawing.

There are also known inventions [3, 4], in which anti-heaving device is made in the form of a system of sun-protection canopy, an insulating layer and an anti-heaving bandage. The canopy is made of galvanized profiled sheet, frost-resistant heat-insulating material is placed around the pylon in an area with radius of at least the depth of seasonal thawing of soil and has height not less than the maximum thickness of snow cover, but not less than 0.5 m. Anti-heaving bandage is made in the form of protective casing made of frost-resistant polymer composite, placed around recessed part of pylon in the area from soil surface to 0.5 - 0.6 depth of seasonal thawing. The space between casing and pylon base surface is filled with an anti-freeze grease.

Disadvantage of proposed technical and technological solutions is complexity of implementation. Another approach to reducing pylon upfreezing is the use of toroidal rubber shell, fixed on base surface in the underground part [5]. The inner space of shell is filled with non-freezing grease. Pylon surface under the shell is also coated with grease. As soil heaves, rubber sheath deforms along the base of pylon with friction minimized by lubrication, preventing vertical movement.

Laminated shell made of polyethylene film functions similarly: porous gaskets with grease are placed between shell layers [6]. Disadvantages of technical solutions are complexity of fixing shells on pylon bases and laboriousness of installation in the process of construction work.

Manuals [7, 8] propose to use heat-shrinkable polymer sleeves to ensure reliable fastening of shells to pylon bases. It is recommended to use modified polyethylene of high and medium density, high molecular weight polyethylene, sevilen and other thermoplastic polymers as the material of sleeves. It is proposed to make its diameter 10% larger than base section dimensions with possibility of shrinkage when heated by 15-150% for convenience of mounting the shell.

Disadvantage of considered technical solutions is also the need to mount shells in conditions of construction sites, since destruction of film materials is possible during transportation of pylons, especially in off-road conditions with shells fixed on pylons.
Structure of pylon foundation proposed in patent [9] is more durable. Structure includes pile and anti-heaving shell. Pile is made in the form of hollow lattice frame, and anti-heaving shell is in the form of monolithic block of polymer material with ring-shaped cross-section that does not freeze with the ground.

In the pit, foundation is placed so that monolithic block is located in active layer, lattice frame is completely below seasonal thawing zone and solidly freezes into it. Disadvantage of the design is technological complexity of manufacturing monolithic block with placement of lattice frame inside it.

In the invention [10], it is proposed to cover the entire lateral surface with polymer compound, after which granular material with fraction size of 0.25 - 5 mm is applied to its part intended for immersion in the ground below seasonal thawing zone to increase adhesion of pile foundation to the ground and improve its bearing capacity simultaneously with decrease in upfreezing. Polymer coating placed in the upper part weakens tangential forces of frost heaving, artificial increase in surface roughness of lower part provides increase in its adhesion to the ground.

Disadvantage of proposed method is possibility of its practical implementation only in factory due to temperature limitations for obtaining high-quality coatings and duration of technological process.

The above brief review presents the most typical technical and technological solutions for reducing frost upfreezing of power transmission line pylons and their foundations when operating in permafrost conditions. Practical recommendations for the use of various types of greases and polymer coatings are given in [11, 12].

It should be noted that modern polymer coatings based on thermoplastics can be applied to metal, concrete, or reinforced polymer composites surfaces, both mechanically and “manually” at construction site conditions. Complexity of application is much lower in comparison with methods of soil treatment in pits.

One of existing obstacles to widespread use of cryophobic antifriction coatings, despite their advantages, is insufficient knowledge of their properties and, which is especially important, their preservation at required level during long-term operation, which determines durability of structures. For example, there is practically no information about variability of adhesion of various coatings to materials used for construction of foundations for power transmission line pylons. Loss of adhesion can cause coating to peel off from foundation and stop working.

Studies on variability of adhesion of Line-X XS-100 (USA) polyurethane coating to concrete during climatic atmospheric aging in conditions of Yakutsk have begun to fill this knowledge gap [13, 14]. The coating was applied using Reactor E-10 hp setup (USA) [15]. Coating thickness was 200 microns. Atmospheric aging of coating samples was carried out according to GOST 9.708-83 [16] for two years. Measurements of value of adhesion to concrete were carried out according to GOST 32229-2013 [17] using Novotest AMC-1 mechanical adhesion meter [18]. Analysis of measurements results of polyurethane coating adhesion to concrete surface shows monotonous decrease by about 12.5% from 1.8 MPa to 1.5 MPa during two-year exposure. Such decrease is quite intense, but not critical, since the area of operation of coating is located below soil surface, out of reach of direct atmospheric precipitation, solar radiation, when exposed to significantly smaller daily drops in ambient air. However, in the future, it is necessary to study separately aging of polymer coating in underground conditions.

As noted above, one of possible directions for reducing vertical displacements of power transmission line pylons during upfreezing is the use of mechanical methods of adhesion of their lower part (under the level of maximum possible summer thawing) with permafrost soil. This approach is quite simple to implement in structures of metal screw piles, in which lower part is made in the form of screw screwed into the leader hole during installation and fixation it in permafrost soil layer [19-20].

Figure 1 shows construction of concrete pylon for power transmission line, in which the same principle is implemented. In the lower part of foundation, across the axis of pylon 1, metal clamps are attached, which are profiles from corner or channel 2, pulled together by steel studs 3 with nuts. Grooves can be made on the surface of foundation for reliable fixation of clamps under the studs. Clamps on the surface of foundation are placed considering results of geotechnical surveys.
Dimensions of clamps, especially profiles used (angles or channels), should not exceed width of the gap between foundation and pit 4 for its installation. During installation process, space between foundation part of pylon and pit wall is filled with soil layer by layer with tamping. Each layer is moistened below seasonal thawing level with water, when it freezes, parts of clamps protruding beyond foundation freeze into the ground. Frozen clamps greatly enhance adhesion of pylon to the ground and prevent its vertical movement. Polyurethane cryophobic coating is applied to pylon surface to seasonal thawing level 5. Combined technical solution that simultaneously reduces tangential forces of frost heaving and enhances adhesion to permafrost soil should minimize vertical movement of pylon.

Figure 1. Reinforced concrete pylon.

5. Practical significance
Information obtained as a result of experiments on resistance of adhesive connection of polyurethane coating to concrete after prolonged climatic exposure, as well as new proposed construction of power transmission line pylon, in which mechanical adhesion of foundation to permafrost soil is implemented, will contribute to increasing durability and reliability of power lines operating in Russian northern and arctic regions.

6. Conclusion
It is shown that the use of polyurethane coatings is promising for reducing frost upfreezing of reinforced concrete pylons for power lines. New pylon structure has been developed with mechanical adhesion of its foundation to permafrost soil and reduced freezing to the ground in its active layer.

7. References
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