POLYMER INSULATORS FOR CONTACT NETWORK DEVICES

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ABSTRACT

The results of studies of the developed designs of polymer suspension, tension, console, fixation and support insulators of the contact network are given. Recommendations for their maintenance and engineering support are suggested.

Keywords: railway, contact network, polymer insulators, types of structures, reliability, maintenance.

Background. *The high congestion of electrified lines makes it necessary to increase the requirements for maintainability and reliability of its most critical units, and also to find more efficient solutions that would minimize the number of failures in the operation of the contact network. It follows that it is necessary to introduce new designs of the contact network, providing higher reliability than existing ones [1].*

One of the promising areas of technical re-equipment and a significant increase in the reliability of the contact network is creation of polymer insulating structures [2]. This is due to the shortcomings of traditional metal-porcelain and metal-glass structures which are high weight, high damageability, not always reliable mechanical strength [3]. Therefore, a system of insulating structures must contain materials that would ensure the stability of electrophysical characteristics during long-term exposure to atmospheric factors.

Objective. *The objective of the authors is to consider different types of polymer insulators used on the contact network.*

Methods. *The authors use general scientific and engineering methods, mathematical apparatus, comparative analysis, scientific description.*

Results. *The replacement of the traditional nodes of the contact network with polymer ones is possible in two stages. The goal of each of them is to obtain a significant economic effect with a minimum of labor costs.*

When implementing the first stage, the polymer insulating structures (insulators) are adequate in their construction length to glass and porcelain. With the exhaustion of the service life, the replacement of traditional insulators with polymer ones does not lead to the reconstruction of the contact network devices. This option operates on electrified lines, its implementation is carried out by the forces of operational personnel.

During major repairs of power supply devices or construction of new lines, the second option is promising, when the suspension, fixation and support structures of the contact network are made entirely of polymer material, i. e. perform simultaneously the functions «bearing structure – insulator».

The design of the contact network made entirely of polymer material continues to be carried out on electrified lines. Some results of this paper are presented in [1].

The probability of failure-free operation P of polymer insulating structures of the contact network must be no less than the value determined from the expression:

$$P(t) = 1 - 0{,}0003t, \quad (1)$$

where t – time since the beginning of operation of insulating structures, years;

0,0003 – coefficient characterizing the annual damage of insulating structures, 1 / year.

The service life of polymer insulating structures of the contact network must be at least 25 years.

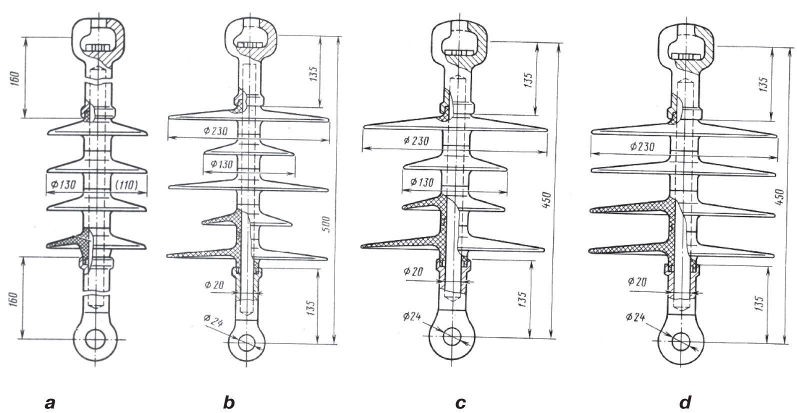
Table 1 shows the strength and durability of fiberglass materials used for network polymer insulating structures.

Let's briefly dwell on polymer insulators [4, 5], used in devices of the contact network.

Table 1

Strength data of fiberglass for polymer insulating structures of the contact network

Type of material	Strength limit, MPa			Elastic modulus, GPa		Coefficient of durability γ_t
	tension	compression	bending	tension	compression	
SPP-P	528	242	580	28–30	19–22	2,22
SPP-EP	632	414	600	37–44	25–36	2,09
SPP-C	785	520	810	35–40	28–36	2,00
SPP-E	850	431	890	52–53	30–38	1,85
SPP-Ev	920	660	1000	52–57	33–38	1,82
SPP-EI	790	435	875	52–55	34–37,5	1,82



Pic. 1. Suspended core insulators:
a) PSKr 70 / L ut – A (B);
b) PSKr 70 / L ut – V;
c) PSKr 70 / L ut – G;
d) PSKr 70 / L ut – D.

Table 2

Design characteristics and results of tests of suspended polymer insulators

Parameters	Values of parameters for insulators of type						
	PSK$_r$ 70/0,41 – A	PSK$_r$ 70/0,39 – B	PSK$_r$ 70/0,67 – V	PSK$_r$ 70/0,67 – G	PSK$_r$ 70/0,415 – E	PSK$_r$ 70/0,45 – Zh	PSK$_r$ 70/0,43 – Z
Destructive mechanical tensile force, kN	138	140	140	140	122	122	122
Construction depth, mm	450	490	450	450	350	350	350
Arcing distance, mm	140	200	180	180	138	138	138
Leakage path length, mm	410	390	670	670	415	450	430
Withstanding voltage kV, not less than: In dry condition	100	100	130	130	95	95	95
under rain	83	90	95	95	55	55	55
50% lightning impulse withstanding voltage	160	150	295	295	130	135	135
Tracking-erosion resistance, h / cycle, not less than	182/6	182/6	182/6	182/6	182/6	182/6	182/6
Radio interference level at operating voltage, dB	20	18	26	26	20	20	20
Weight, kg	1,6	1,52	2,63	2,63	2,3	2,3	2,3

Suspension insulators. *The wide use of porcelain and glass insulators is explained by the convenience of bundling garlands for any voltage, the mastery of mass production technology.*

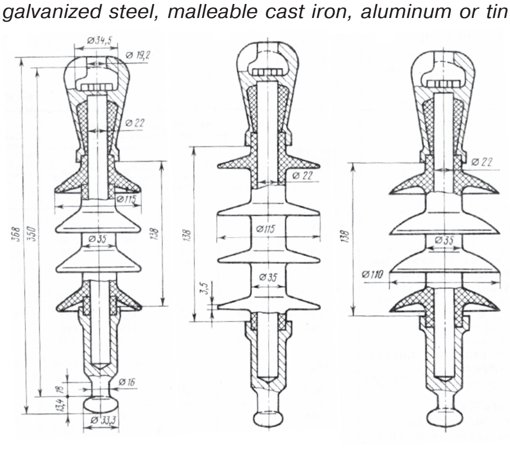
On DC lines, suspension disc insulators are used almost everywhere, connected to garlands of two, with the exception of the suspension of a supporting cable on insulated flexible crossbars.

On AC lines, these insulators are used in garlands, they are connected in three, and in areas of increased pollution, in four and five.

Suspension polymer insulators are intended to replace garlands of porcelain and glass insulators, and by their characteristics should be no worse than garlands used in DC and AC sections. At the same time, all the characteristics of polymer insulators should be preserved in the operating temperature range (–60˚ / +50˚C).

The protective surface of polymer insulators, as a rule, is developed. Such a design solution allows to reduce the construction overall dimensions of insulating structures, while maintaining the specific length of the leakage current.

It is recommended to make the end fittings (end terminals) of suspension polymer insulators from galvanized steel, malleable cast iron, aluminum or tin bronze. The end terminal can be of two options: a pestle or a link component.



a ***b*** ***c***

Pic. 2. Suspended rod insulators for DC contact network:
a) PSKr 70 / 0,415 – E; b) PSKr 70 / 0,45 – Zh; c) PSKr 70 / 0,43 – Z.

Several types of polymer suspension insulators are being operated on electrified roads. The first two types of suspension insulators are similar to each other. For PSK$_r$ 70 / L_{ut}– A insulators (see Pic. 1a), the diameter of the ribs is 130 mm, for PSK$_r$ 70 / L_{ut}– B, the diameter of the ribs is 110 mm.

The third type of insulators PSK$_r$ 70 / L_{ut}– V (Pic. 1b) is assembled from two varieties of alternating ribs with a diameter of 230 and 130 mm. The difference between PSK$_r$ 70 / L_{ut}– G insulators (Pic. 1c) from PSK$_r$ 70 / L_{ut}– V insulators is that the ribs of a larger diameter (230 mm) are installed only at the end terminals.

The design of PSK$_r$ 70 / L_{ut}–B and PSK$_r$ 70 / L_{ut} – G suspension insulators makes it possible to create the insulator free from contamination or ice zones, which favorably affects the discharge characteristics. These types of insulators work well in a polluted atmosphere (IV–VII – pollution areas).

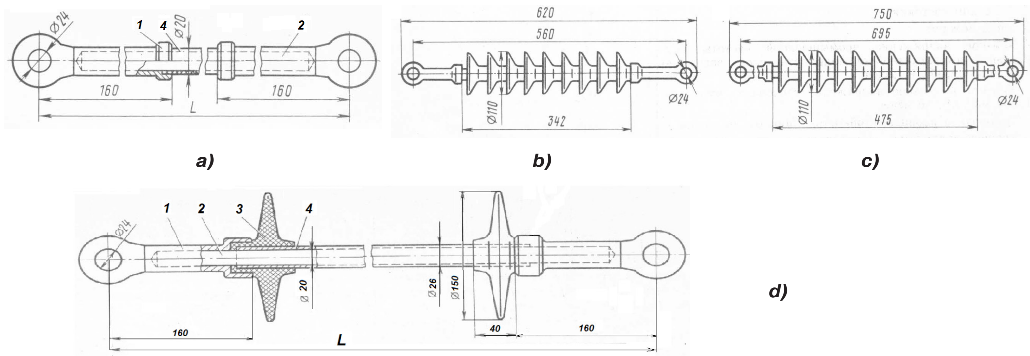
On the AC road network, PSK$_r$ 70 / L_{ut}–D insulators are used (Pic. 1d). They are made of cone-shaped silicon-organic ribs with a diameter of 230 mm. And it is noteworthy that the advantage of this design over the previously considered ones is that at the same leakage current length, PSK$_r$ 70 / L_{ut}– D insulator has a smaller construction depth. They are recommended to be used in places with tight dimensions.

The network of DC roads continue to operate the developed three types of insulators (Pic. 2). PSK$_r$ 70 / L_{ut} – E (Pic. 2a) is made of ribs with a diameter of 110 mm, the upper end terminal with a pestle socket is made of cast iron. For PSK$_r$ 70/0,45 – Zh (Pic. 2b) and PSK$_r$ 70/0,43 – Z (Pic. 2c), the protective shell is solid, all-piece. It allows reducing the number of joints, assembly operations during manufacture. The solid-cast protective shell requires one, but more complex block form, as well as addressing the issues of joint heat treatment of the shell thus molded with the rest of the insulator.

The PSK$_r$ 70/0,45 – Zh has the semi-conical shape of the ribs, while PSK$_r$ 70/0,43 – Z is domed. The use of this form is caused by the existing difficulties in obtaining a solidly shaped conical shape of the ribs when it is formed, but the shape of such protective shells provides the same advantages to the insulator as the cone-shaped one.

Table 2 shows some of the structural characteristics of polymer insulators, as well as the results of their tests.

Tension insulators. *Tension polymer insulators are widely used in the nodes of the contact network [6, 7]. To ensure the necessary length of the path of leakage and*



Pic. 3. Tension polymer rod insulators: a) insulator NSFt with fluoroplastic protective tube; b) insulator NSKr 120 / 0,95; c) insulator NSKr 120 / 1,2; d) insulator NSFtKr 120 / 0,9 with the combined smooth-ribbed protective cover; 1 – the end terminal; 2 – fiberglass rod; 3 – ribs made of silicone rubber; 4 – fluoroplastic tube.

tracking stability, they can be manufactured with a smooth protective cover (see Pic.e 3a), with a ribbed or combined smooth-ribbed protective cover (see Pic. 3b, c, d).

Insulators with a smooth protective cover have minimal transverse dimensions, but a large construction depth; ribbed insulators, on the contrary – the minimum construction depth, but large transverse dimensions. With regard to the construction depth, the intermediate position (with the same length of the leakage path) is occupied by tension insulators with a combined protective cover.

The diameter of the fiberglass rod of tension insulators is chosen based on the value of the normalized breaking force. Table 3 shows the minimum allowable diameters of fiberglass rods for polymer insulators of the contact network, depending on the selected safety factor.

Usually rods of diameter 20 mm are used. Fluoroplastic tube is with a wall thickness of 2–3 mm. The space of the gap between the rod and the tube along its entire length is sealed, that is, it is filled under pressure with silicone vaseline and paste.

Polymer insulators are several times more expensive than porcelain, their release is limited. Therefore, insulators of the NSF type are recommended to be applied rationally, first of all in such constructions and nodes of the contact network, where high impact strength of polymer insulators will increase the reliability of the contact network (in places of damage to of porcelain insulators by unauthorized persons); low mass and transverse dimensions of the insulators will have a favorable effect on the dynamic characteristics of the structure (for example, insulating joints of anchor sections); a long length of smooth-rod insulators will increase the reliability of isolated consoles (the possibility of overlapping by birds of isolation in stretched linkage rods); in cases where the use of porcelain insulators is either generally impossible (in nodes with limited dimensions) or inefficient (for example, in areas with severe air pollution).

The antipollution characteristic of fluoroplastic is several times higher than that of porcelain and other polymeric materials, from which a protective tracking-resistant cover for a fiberglass rod can be made. Therefore, in this respect, smooth-rod tension polymer insulators with fluoroplastic protective tube have an indisputable advantage in comparison with porcelain and glass.

The probability of failure-free operation of polymer insulators NSF_t with a 20 mm fiberglass rod is high, not lower than that of insulating elements and is $1,1{\cdot}10^{-7}$. However, on lines where the speed of the trains reaches 200 km / h, it is recommended to use double insulators NSF_t.

Polymer tension insulators with a developed surface (ribs, caps, discs) are being intensively developed in recent years. This insulator consists of a fiberglass rod of 22 mm, a protective cover in the form of bushings with conical ribs 110 mm. The NSC_r 120 / 0.95 isolator (Pic. 3b) is designed for use in areas with a degree of atmospheric pollution I–IV. For areas with a degree of contamination V–VII, NSC_r 120 / 1.2 tension insulator with a leakage path length of 1200 mm is recommended (Pic. 3c). The main parameters and characteristics of tension insulators are given in Table 4.

On the Russian roads, polymer tension insulators with a combined protective cover type NSF_tK_r120 (Pic. 3d) have been developed.

The insulator consists of a fiberglass rod with a diameter of 20 mm, a protective cover made of a fluoroplastic tube and two sleeves made of silicone rubber with 150 mm disc ribs, two end terminals of the «eye» type. In the combined protective case the main role is played by the fluoroplastic protective tube. On the ends of it «sleeves-ribs» are mounted, on the one hand they have the form of a ring and are condensing in end terminals, excluding the penetration of moisture under the cover.

Two ribs made of silicone rubber with a diameter of 150 mm with a total length of the path of leakage of 265 mm make it possible to produce insulators NSF_tK_r120 approximately 200 mm shorter (20–30% with a shorter distance between the end terminals) of the same length of leakage path for insulators of the type NSF_t70.

The presence of ribs also positively affects the increase in electrical safety conditions when works are made at the contact network. This is achieved by the fact that the «sleeve-rib» is a kind of psychological barrier of danger.

Depending on the degree of danger of the equipment and devices of the contact network, polymer insulators can be manufactured with different color gamut.

Table 3

The minimum permissible diameters of fiberglass rods for polymer insulators of the contact network, depending on the chosen safety factor K = 2,7–5,5

Type of fiberplastic	Type of insulator			
	Tension (suspension) class 120 kN	Fixing	Console	Supporting
SPP-E	20–33,6	26–41,2	36,0–55,2	36,0–52,0
SPP-Ev	20–32,0	26–39,8	36,0–53,4	36,0–52,0
SPP-EI	20–34,5	26–42,0	36,0–56,3	36,0–53,0

Table 4

Constructive characteristics and test results of tension polymer insulators

Parameters	Values of parameters for insulators of type						
	NSF_t 70 (120)/0,4	NSF_t 70 (120)/0,6	NSF_t 70 (120)/0,8	NSF_t 70 (120)/1,0	NSF_t 70 (120)/1,2	NSK_r 120/0,95	NSK_r 120/1,2
Construction depth, mm	720	920	1120	1320	1500	1000	1200
Leakage path length, mm	400	600	800	1000	1200	950	1200
Withstanding voltage kV, not less than: In dry condition	95	145	>200	>200	>200	140	150
under rain	82	100	150	185	215	100	110
50% lightning impulse withstanding voltage	150	220	296	>300	>300	200	220
Tracking-erosion resistance, h / cycle, not less than	182/6	182/6	182/6	182/6	182/6	182/6	182/6
Radio interference level at operating voltage, dB	5	5	10	10	10	10	10

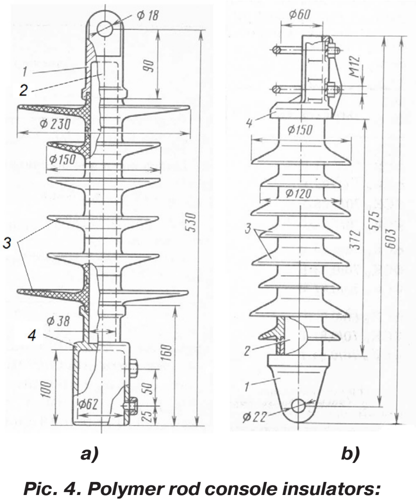
During tensile testing, the NSF_tK_r120 insulators collapsed (the tear off of the eye of the end terminal from its cylindrical part for welding, the sliding of the end terminal from the fiberglass rod) at a load of 130–150 kN.

Console insulators. *Polymer console insulators are designed to be installed in the struts of isolated consoles. They are under the influence of a complex system of loads, which are always brought to the longitudinal, transverse forces and bending moment. The transverse force does not significantly affect the stressed state of the insulator. Therefore, the main load, which determines the stressed state of the insulator, is the longitudinal force and the bending moment.*

The main requirements imposed on console polymer insulators from the mechanical point of view is that the breaking mechanical load under tension must be at least 70 kN, with bending in the plane of the eyelet – not less than 5 kN, and the breaking bending moment – not less than 2,5 KN · m. For the manufacture of console rod insulators it is recommended to use fiberglass rods with a diameter of at least 35 mm.

Insulators working in a polluted atmosphere must have a ribbed protective coating of fluoroplastic or silicone rubber.

The polymer rod console insulators developed in Russia have cone-shaped ribs made of silicone rubber.



a) b)

Pic. 4. Polymer rod console insulators: a) KCK_r70 / 0,94 – G; b) KSK_r70 / 0,9 – D; 1 – end terminal; 2 – fiberglass rod; 3 – ribs made of silicone rubber; 4 – end terminal of the pipe for the console.

The design of the protective shell of console insulators is identical to the protective shell of suspension insulators.

Insulators KSK_r70 / L_{ut} – A are assembled from ribs with a diameter of 130 mm, and insulators KSK_r70 / L_{ut} – B – from ribs with a diameter of 150 mm. Polymer rod console insulators KSK_r70 / L_{ut} – V are assembled of two varieties of alternating ribs with diameters of 230 and 150 mm; for insulators KSC_r70 / L_{ut} – G, ribs of a larger diameter are installed only at the end terminals. The insulators KSK_r70 / L_{ut} – D, as well as the insulators PSK_r70 / L_{ut}–G, are assembled from ribs with a diameter of 230 mm. These designs have different leakage path lengths. The end terminals of such types of insulators (Pic. 4a) are made of steel. The connection with the fiberglass rod of the end terminals is carried out by gluing method.

The design of the polymer console insulator KSK_r 70 / 0,9 – E deserves special attention. It is assembled (Pic. 4b) from two alternating ribs with diameters of 150 and 120 mm, with two ribs mounted on their metal part in order to increase the length of the insulating part. The end terminals are made of cast iron.

The characteristics of some polymer console insulators are given in Table 5.

Fixation insulators. *On the direct current lines for all fixation, except for flexible, disc shaped porcelain insulators PTF-70 with a special cap, which has an internal thread to fix the pipe diameter of 1 inch are used.*

For flexible fasteners, PR-70 insulators are used.

On the lines of alternating current (and sometimes also at constant current), rod insulators of the types IPS and VKL are used as fixing ones. Therefore, the electromechanical characteristics of polymer fixation insulators should not be lower than the characteristics of the corresponding porcelain insulators.

Polymer rod fixation insulators according to the structural design of the insulating part are analogous to the polymer console modifications FSK_r70 / L_{ut} – A (B, V, G and D). The only difference is that special end terminals are used (Pic. 5a). The end terminals are made of steel, they are planted on a fiberglass rod by gluing.

In FSC_r70 / 0,9 – D insulators (Pic. 5b), the protective shell is made of ribs of 120 mm diameter. One (located at the end of the «eyelet» type of the end terminal), as well as in console insulator, is mounted on the metal part of the end terminal to increase the length of the insulating part.

The design characteristics of some types of fixation isolators and test data are given in Table 6.

Fixation polymer insulators can be used for fixing AC and DC diodes of the contact network.

Support insulators. *Support insulators are designed for insulation and mechanical fastening of current-carrying parts in electrical apparatus and for the installation of*

Table 5

Design characteristics and test results of console polymer insulators

Parameters	Values of parameters for insulators of type					
	KSK$_r$ 70 /0,84 – G	KSK$_r$ 70 /0,94 – G	KSK$_r$ 70 /0,9 – E	KSK$_r$ 70 /1,09 – D	KSK$_r$ 70/0,62 – A	KSK$_r$ 70/1,18 – B
Construction depth, mm	375	425	574	440	464	650
Leakage path length, mm	840	940	912	1090	592	778
Withstanding voltage KV, not less than: In dry condition	170	180	160	160	130	163
under rain	140	150	120	125	118	118
50% lightning impulse withstanding voltage	250	260	225	245	206	275
Mechanical destructive force, kN at tension at bending	1488	1508	1508	1508	1508	1508
Tracking-erosion resistance, h / cycle, not less than	182/6	182/6	182/6	182/6	182/6	182/6
Radio interference level at operating voltage, dB	5	5	5	10	18	20
Weight, kg	4,08	4,32	6,82	4,02	1,43	2,03

Table 6

Constructive characteristics and test results of fixation polymer insulators

Parameters	Values of parameters for insulators of type					
	FSK$_r$K$_r$ 70 /0,9 – E	FSK$_r$ 70 /1,09 – D	VKL- 60/3 – 4	FSK$_r$ 70/0,67 – V	FSK$_r$ 70/0,62 – A	FSK$_r$ 70/1,24 – B
Construction depth, mm	538	440	540	360	475	641
Leakage path length, mm	873	1090	720	400	538	704
Withstanding voltage KV, not less than: In dry condition	180	160	150	150	145	170
under rain	155	125	100	105	110	140
50% lightning impulse withstanding voltage	235	255	200	230	210	260
Mechanical destructive force, kN at tension at bending	1438	1688	705	1508	1508	1508
Tracking-erosion resistance, h / cycle, not less than	182/6	182/6	–	182/6	182/6	182/6
Radio interference level at operating voltage, dB	5	15	–	5	15	20
Weight, kg	6,82	3,54	8,3	2,85	1,33	2,08

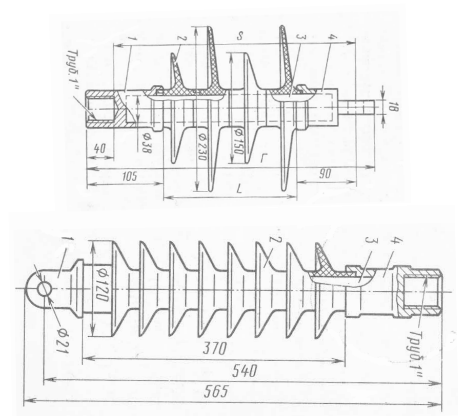
current-carrying wires (buses) of power distribution devices.

In the process of operation, the supporting insulators are exposed to bending loads caused by electrodynamic forces in short circuits, which create forces normal to the axis of the insulator. In some cases, the supporting insulators experience tensile, compressive or torsional stresses.

Polymer supporting insulators of the contact network are mainly designed for sectional disconnectors and dischargers. Some types of polymer support insulators can be used in basic protective equipment used for working under voltage on the contact network, in particular, on insulating towers, DR handcars, motor-rail car AGV. From the mechanical point of view, the main requirement for support polymer insulators is that the breaking load at tension (compression) should be at least 70 kN, at bending – 8 kN, and the breaking bending moment – not less than 4 kN · m. Polymer support insulators in the arrangement of the insulating part are similar to polymer console insulators. As can be seen from Pic. 6, the distinguishing feature of insulators OSK$_r$70 / 0,66 – B and OSK$_r$70 / 1,09 – D is the presence of special end terminals

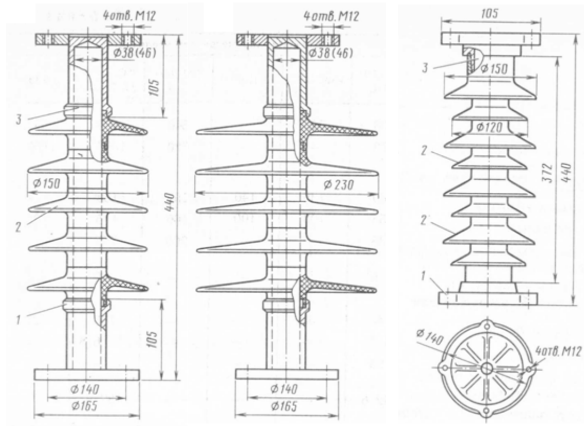
a)

b)



Pic. 5. Fixation rod insulators: a) FSK$_r$70 / L$_{ut}$ – V; b) FSK$_r$70 / 0,9 – D; 1,4 – terminal grip; 2 – ribs made of silicone rubber; 3 – fiberglass rod.

Pic. 6. Polymer support insulators:
a) OSK_r70 / 0,66 – B;
b) OSK_r70 / 1,09 – D;
c) OSK_r70 / 0,8 – E;
1 – end terminal; 2 – ribs made of silicone rubber;
3 – fiberglass rod.



a) b) c)

Table 7

Constructive characteristics and test results of support polymer insulators

Parameters	Values of parameters for insulators of type					
	OSK_r 70/0,66 – B	OSK_r 70/0,88 – V	OSK_r 70/0,81 – G	OSK_r 70/0,8 – E	ONS-35 – 500	KO – 400 S
Construction depth, mm	440	440	440	439	420	550
Leakage path length, mm	660	880	810	911	620	1050
Withstanding voltage kV, not less than: In dry condition	150	160	160	155	120	135
Under rain	120	130	125	110	80	90
50% lightning impulse withstanding voltage	250	250	250	248	210	220
Mechanical destructive force, kN at bending	15*	15*	15*	11,8	6	10
Radio interference level at operating voltage, dB	18	16	16	16	–	–
Weight, kg	5,19	5,97	5,71	7,94	15,45	37,8

* The insulator withstood the load without destruction.

made of steel. In insulators OSK_r70 / 0,8 – E cast iron end terminals are used (Pic. 6, c).

Characteristics of some types of support insulators are given in Table 7, there are also given the characteristics of traditional porcelain insulators ONS-35–500 and KO-400S.

Conclusion. *The article presents reliability scale and the prospects for the use of polymer materials in the structures of the contact network.*

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