<u>**Design, Mechanical Aspects And Other Subjects of Compact EHV OHL Technology**</u>

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Introduction

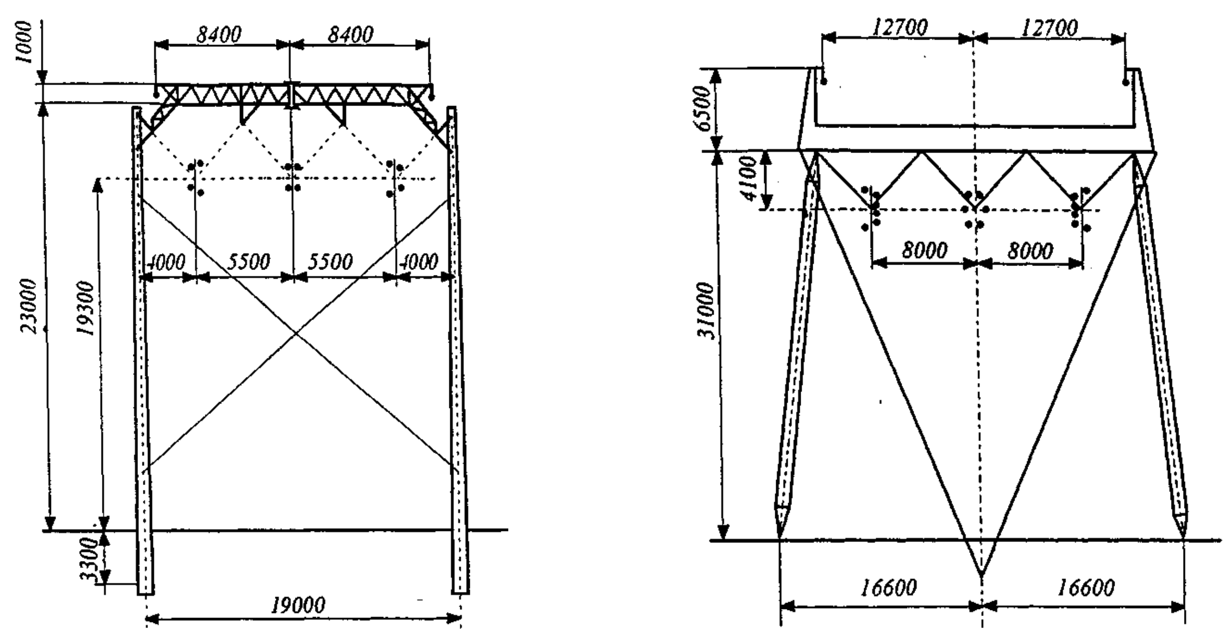
An increase in transmitting capacity determined by stability conditions can be achieved in long EHV overhead transmission lines through reducing surge impedance of the line. Surge impedance significantly decreases at reducing the interphase distance. Gradients of electric field on surfaces of phase conductors can be kept within acceptable limits through the increase in the number of subconductors in bundled phase and their optimum mutual positioning [1-3].

1. Compact EHL OHLs with a horizontal phase conductor arrangement

Transmission line of increased transmitting capacity with elliptic configuration of subconductors in a bundled phase allows to increase transmitting capacity of the line by 2 or more times.

The electrical characteristics of transmission line are determined mainly by mutual position of phases and their subconductors within a span.

To decrease surge impedance of a compact overhead line as much as possible one needs to choose the smallest distance between phases and the smallest distance from conductors to grounded tower structure elements. It was found [4] that the best results for 330 and 500 kV compacted lines with horizontal phase positioning may be obtained when using tangent portal towers of enveloping type per Fig. 1.



a *b*

Figure 1. Schemes of tangent portal "enveloping"-type towers for compact overhead lines:

a – on the basis of armor-concrete racks for 330 kV overhead line;

b – metal towers with strings for 500 kV overhead lines

But at compact line designing it should be taken into consideration that closeness of rounded elements of such a tower to conductors leads to local increase of electric field gradient on the surfaces of subconductors by 10-13% [1].

For compact transmission lines based on phase bundle of oval configuration it is possible to provide an increased bundle size in the lowest point of a span and reduced size at a supporting clamp on a tangent tower through different mechanical tensions in subconductors [2]. In such design a distance between subconductors varies along a span, and equivalent specific inductance and capacitance of the line have to be determined by averaging their values along the span (i.e. taking into account the distribution along the span of geometrical dimensions). Such averaged values will determine the transmitting capacity. The change in inductance along the span is attributed mainly to the changing height above the ground, similarly to its change in traditional transmission lines with constant distance between subconductors in a bundle. The capacitance of the compacted line with variable spacing between subconductors varies along the span more drastically than in usual lines, as conductors become closer to the tower.

1.1. A 330 kV compact OHL

During designing a new 330 kV compact transmission line between Pskov TPP and Novosokolniki [4] 11 different versions of phase bundling were evaluated from the points of view of technical and economical characteristics. Version "E" of Fig. 2 was chosen as the most acceptable. It uses 4 ACSR conductors (AC-150/34 per Russian Standard GOST 839-80) with aluminum crossection of 150 mm^2 and OD 17.5 mm –see Table 1. For comparison Table 1 also shows the standard bundling for 330 kV lines adopted in Russia.

An increase in the “natural power” of the line amounts to 644MV and is reached with h_{kp} equaled to 5,5 (version "C" in Table 1), but a considerable increase in the number of towers would he required in this case that is not desirable from the economical point of view.

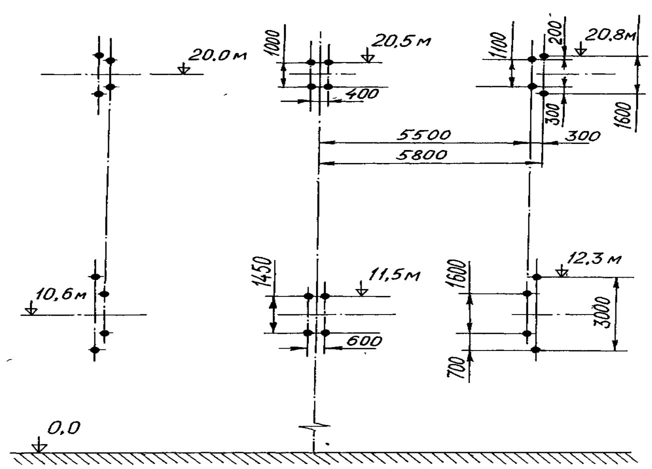


Figure 2. Position of subconductors in phase conductor bundle for compact overhead line in the window of tangent tower (upper position) and in a span (lower position) with equal charges on the subconductors*:* for 330kV.

Table I

Parameters and characteristics of OHL conductors		Variants of conductor design		
		А	Б	В
The number and cross-section of subconductors		2xAC 300/39	4xAC 150/34	
r_0, cm	Subconductor radius	1,2	0,875	
nr_0, cm		2,4	3,5	
H_{eq}, m	Equivalent conductor height	13,5	11,2	

$H_{m.p.}$., m	Subconductor size in the vertical direction	middle phase	—	1,6	
$H_{o.p.}$., m		outer phase	—	2,6	5,5
a, cm	Subconductor spacing		40		
0,8E_0.kV/cm	Permissible gradient at S=1,02		29	30,26	30,26
$E_{m.p.}$ kV/cm	Maximum electric field gradient on subconductor surface	middle phase	28,11	29,94	30,12
$E_{ко.р}$. kV/cm		outer phase	22,58	26,97	40,04
Z_B Ohm	Surge impedance		277	180	169
C, pF/m	Specific capacitance		12,33	19,1	20,3
$P_{нат}$. MW	Natural power		393	605	644

This 330 kV line drastically differs from traditional 330 kV lines in the distance between phases: it was set at 5.5 m instead of 9 m (for unified steel towers of П -330-5 type) or even 12.8 m (for reinforce-concrete towers of ПБ-330-1 type). Such small distance can be practically obtained only using tangent portal towers of "enveloping" type (Fig. 3). It should be noted here that phase-to-phase distance of 5,5 m (Fig. 1-a) is even less than minimum standardized distance equal to 6,0 m.

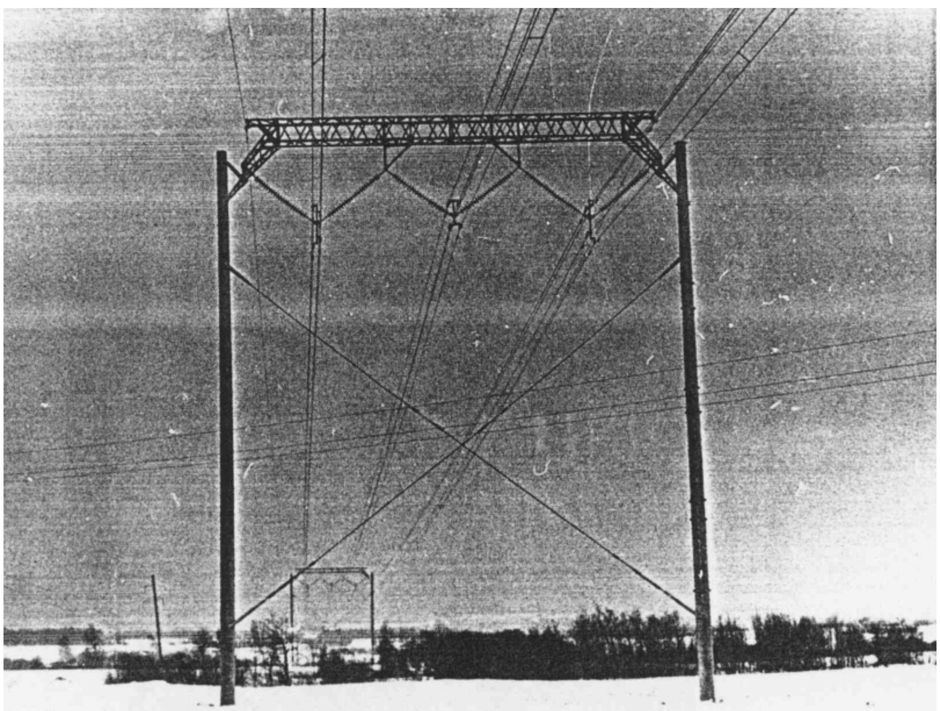


Fig.3. A suspension tower of enveloping type on the 330 kV Pskovskaja HPS–Novosokolniki OHL

Such small distance can be accounted as a permissible one providing the following factors. Standard norm requirements refer to traditional transmission lines with conductors suspended freely on vertical insulators strings, which deviate under wind influence together with conductors allowing conductors to move closer to the tower.

With a V-type strings on tangent towers a wind-forced conductors oscillation near the tower is strictly limited. In this case the required phase-to-phase distance *d* is determined by phase movement in a mid-span and can be estimated by the formula:

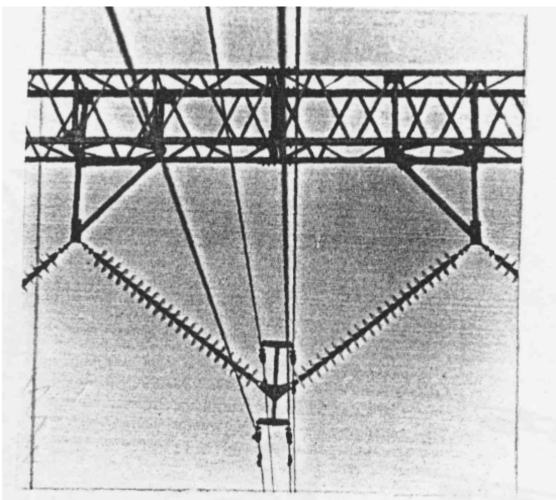
$$d = \frac{V}{110} + 0{,}14\sqrt{fb} \qquad (1)$$

where V is line voltage, f is the sag in a standard span, in meters, b – thickness of ice on a conductor (but not more than 20 mm).

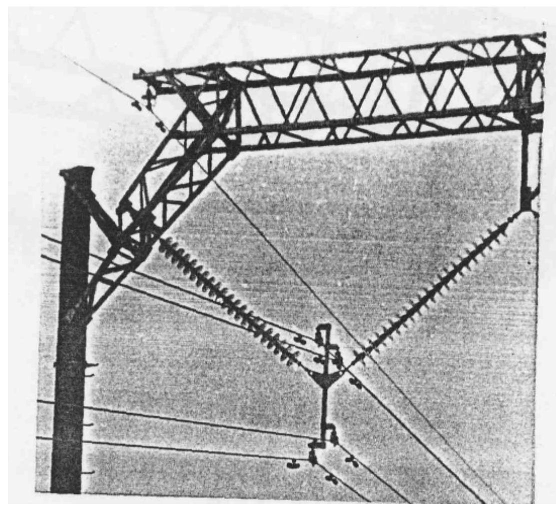
Transmission line length in our case was 145,2 km. The line is going through the Grade 1 ice- zone (104,2 km) and the Grade 2 zone (41,0 km). According to the formula above, for the Grade 2 zone, with b = 10 mm and f = 10,5 m, we'll get:

$$d = \frac{330}{110} + 0{,}14\sqrt{10{,}5 \cdot 10} = 4{,}95 \quad m.$$

Insulating suspension of bundled phase is performed on V-type insulator strings with angle between chains of 100 degrees (Fig. 4). This angle secures reliable conductor's fitting practically in all operating conditions and according to international practice can be even a little less (up to 90°) [5].



a

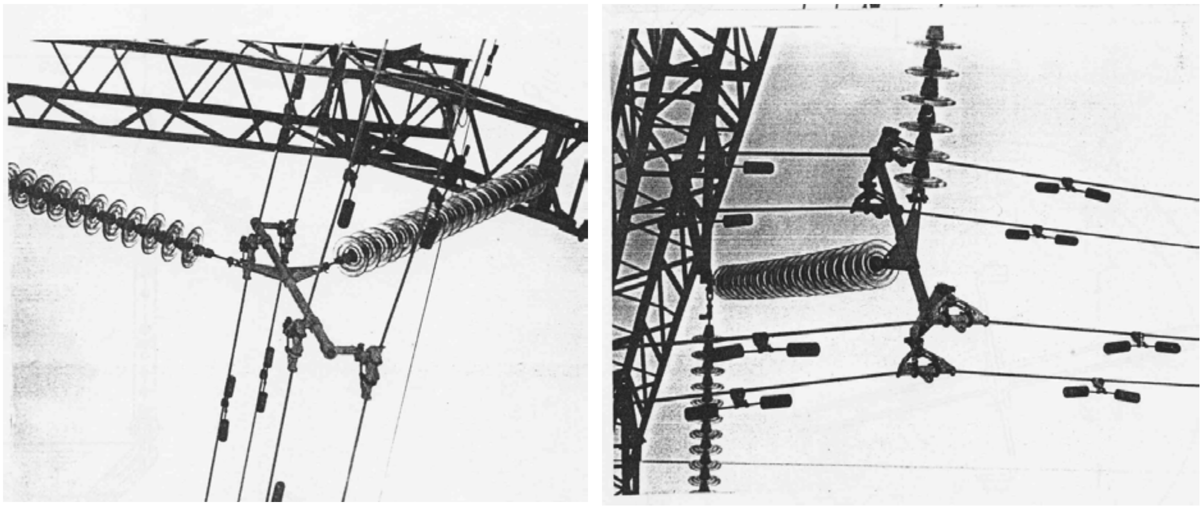


b

Figure 4. Phase conductor suspension on a V-type insulator string for Pskov TPP-Novosokolniki 330kV overhead line:

a - for the outmost phase conductor, *b* - for the middle phase conductor

Unusual geometry of bundle conductors for a new 330kV line required a new approach in supporting clamps design. Russian Electric Power Research Institute VNIIE has suggested a new design of supporting clamp - the so-called “elk-tree scheme" for suspension of bundle conductors in outer phases. Such clamps were designed for suspension of middle and outer phases (see Fig. 5).



а *б*

Figure 5. Supporting clamps for bundle conductor suspension on Pskov TPP-Novosokolniki 330 kV overhead line:

a - for the outmost phase conductor, *b* - for the middle phase conductor

The clamp consists of vertical tube-string and support arms attached to it on which via hinge-connected slipping devices conductors are hanged. There is no serial production in Russia of slippers on supporting arms with vertical axis of rotation designated for the conductor AC 150/34 type according to GOST 839-80. Because of that as a basis for new supporting clamps the clamp of ПГ 3-10-type normally designated to fit lightning arrester wire on supporting poles was used. The supporting clamp design (Fig. 6) fixes bundled phase to the roll balance having two degrees of freedom.

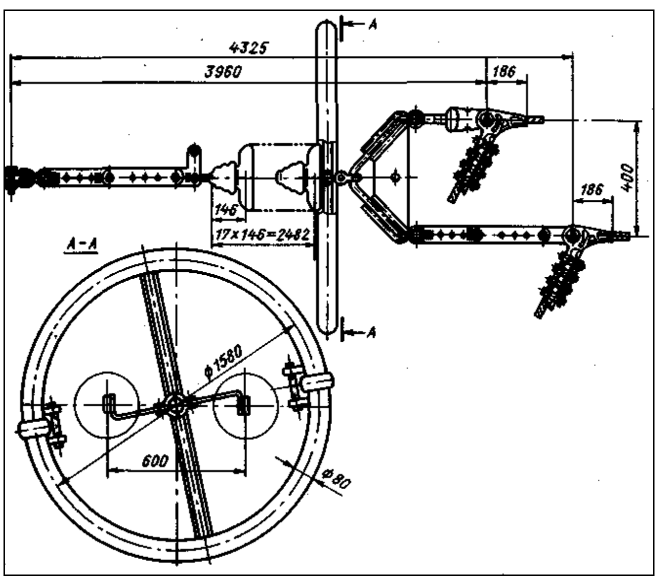


Figure 6.

Tensed insulator string design for Pskov TPP-Novosokolniki

Hinge connection of rolls with balance arm secures an optimal operation of clamp in regimes with wind loads perpendicular to line route; hinge for rolls rotation around the vertical axis is required in emergency conditions in case of tripping of one conductor in the bundle phase. This case is considered to be of low probability, so for the first 330 kV compact line the application of such non-standard clamps can be considered as permissible, also taking into account that on 330 and 400 kV transmission lines in West Europe supporting clamps for bundle phases have double-hinge fitting of rolls to a balance arm.

Unified metallic tangent towers of Y330-3-type with fixation of insulator strings in two points located horizontally were used. To fix line conductors to tangent towers special double insulator strings consisting of ПС 160-В insulators were designed (Fig. 6 and 7). The dead end fitting of a subconductor is made using a serial bolt clamps НБН-3-6-type in pairs over balance arm shoulders 2KY-12-1 fitted to two insulators strings.

To provide necessary spacing between subconductors inside the span bi-conductor spacers installed according to schemes of Fig. 8 were used. Mutual fixation of upper and lower pairs of conductor is provided by bi-conductor spacers РП-I-3-400, which are in serial production.

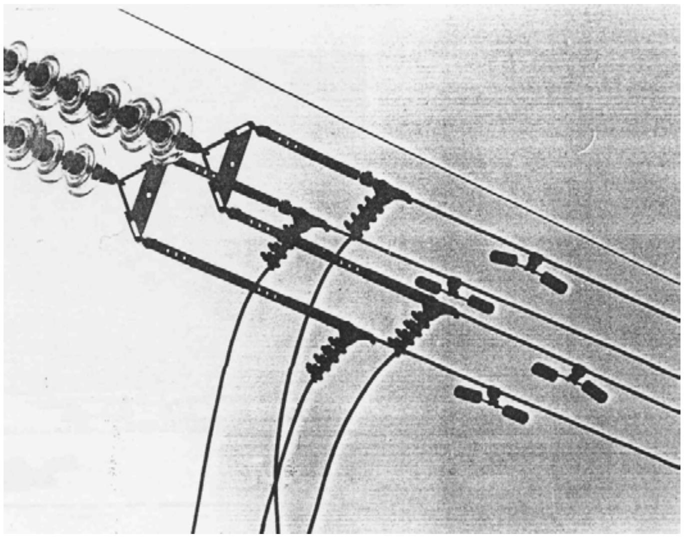


Fig. 7. Insulator string design for fitting of a 4-subconduc-tors bundle conductor (AC 150/34) to the anchor-tangent unified tower for 330kV compact overhead line.

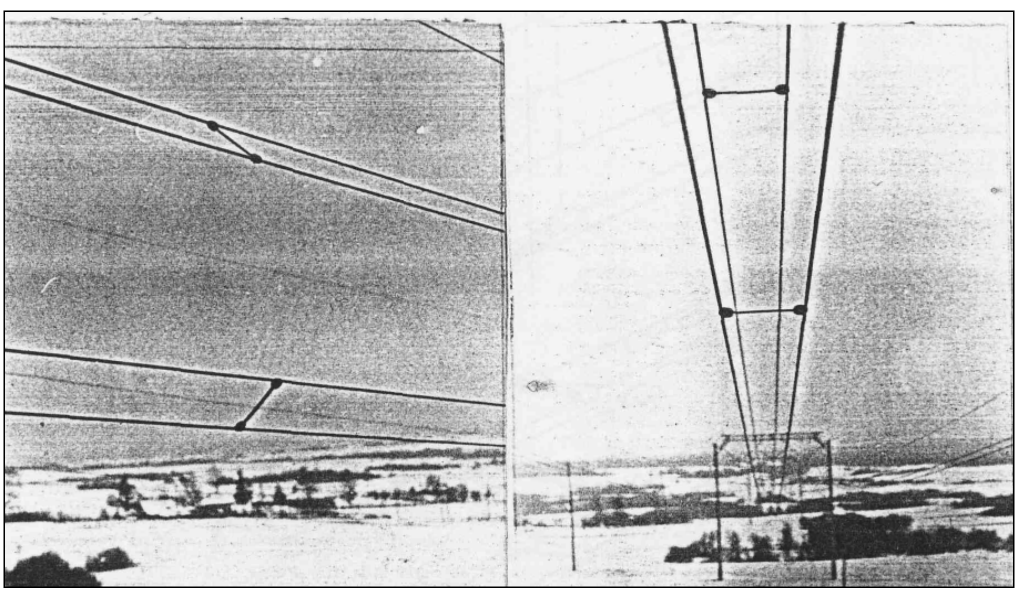


Fig. 8. Subconductor of bundle conductor fixation by the spacers for Pskov TPP-Novosokolniki 330 kV overhead line:

a - on the outmost phase conductor,

b - on the middle phase conductor

Distance along a span between spacers on upper and lower pairs of subconductors is set to 30m. Estimating the probability of appearing dangerous line conductor galloping it should be taken into consideration that upper and lower pairs of subconductors in both middle and outer phases are located far enough from each other.

To suppress possible vibration Stockbridge dampers were installed where necessary as recommended by norms for transmission lines with bundles of two subconductors (Fig. 5 and 7). It also should be taken into account that lower pairs of subconductors in the middle phase have mechanical tension by 5% lower, and for outer phases by 10% lower than upper pairs. This situation may permit to exclude the installation of vibration dampers on lower pairs. At the assembled portion of the discussed line measurements of conductors oscillation would be performed to evaluate vibration levels and estimate a possibility to lessen the number of dampers installed- up to the full their exclusion.

Danger of subspan oscillation appearance could be estimated from a long-time maintenance experience for a large 330 kV grid with phases bundled into two subconductors. These lines were generally very reliable. For traditional 330 kV lines bundled into two subconductors AC 300/39 the ratio of a distance between subconductors "a" to their diameter "d_0" was 1.6, whereas for pairs of subconductors AC150/34 in the middle phase on the transmission line Pskov-Novosokolniki it equals to 23. That permits to expect a low probability of subspan oscillations. The nearest subconductors located horizontally in outer phases are far enough from each other and shifted vertically by 265mm. Under these conditions the appearance of subspan oscillations of outmost phases conductors practically is impossible because of lack of inter-influence between subconductors in aerodynamic oscillations. Foreign experience of this effect shows that the similar result can be usually achieved by artificial changes irregulars configuration of bundle conductors [6] .

The first Russian compact 330 kV transmission line, together with a thermal power plant, were scheduled for commissioning in the end of 1991. Its first erected section was used to perform recordings of vibration and subspan oscillations on subconductors of the middle phase using up-dated vibration measurement instrumentation.

1.2. An experience in designing and testing models of insulator strings and line fittings for a compact 500 kV OHL

The experience obtained at designing and assembling the first compact 330 kV line Pskov-Novosokolniki line is applied at present lime to the first compact 500 kV line Boguchansk hydro power plant - Kansk that is under construction. Several options of power supply from Boguchansk HPP into the power grid were considered: consisting of three 500 kV lines with phase of 3 x AC 330/43 conductors (natural power of each line - 856 MW), or two 500 kV lines with phase of 6 x AC 240/56 (natural power per line-1760 MW, or taking into account the influence of variable dimensions of the bundle along the span per Fig. 9 -1720 MW).

In the process of line assembling the full mechanical tension will be applied only to the upper pair of subconductors in the bundle; lower pairs will experience lesser tension. In this case vibration protection with standard Stockbridge dampers is needed on the upper pair equipped with spacers (Fig. 10). Here damper placement follows norms established for bi-conductor bundles. On subconductors not connected to each other by spacers, dampers should be installed according to norms adopted for single conductor phases.

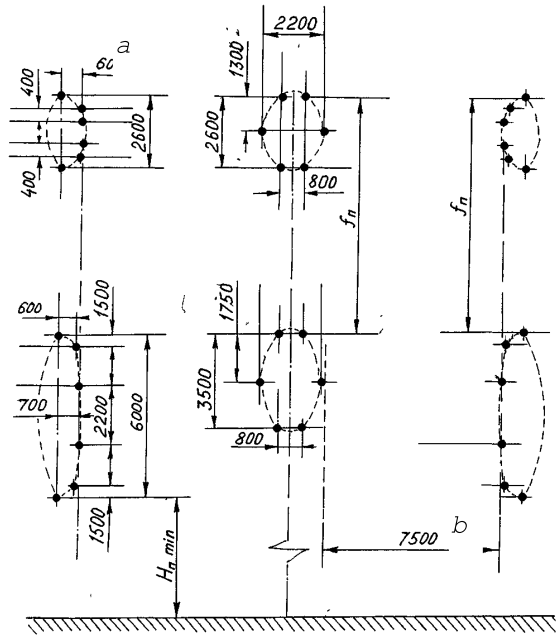


Figure 9. Position of subconductors in phase conductor bundle for compact overhead line in the window of tangent tower (upper position) and in a span (lower position) with equal charges on the subconductors*:* for 500kV overhead line

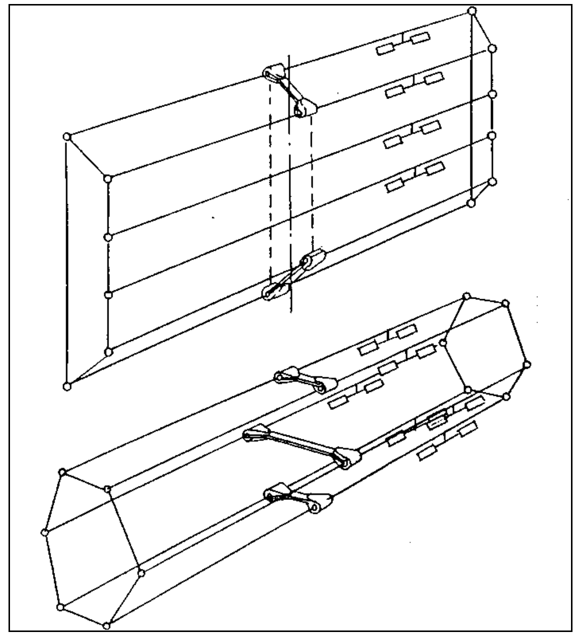


Figure 10. Installation schemes of coupled spacers and vibration dampers on the bundle conductors for the 500kV overhead line:

a - on subconductors of outmost phase conductor,

b - on subconductors of middle phase conductor,

1 - bundle conductor subconductors,

2 - coupled spacer,

3 - vibration damper

Positions of subconductors in a bundle is fixed by installation of bi-conductor spacers in horizontal pairs of middle phase and only on upper and lower pairs of outer phases.

The minimum phase-to-phase distances that are adopted for compact transmission lines with free suspension of horizontally positioned phases are prescribed by Electrical equipment construction rules. According to a Draft of new edition of these Rules such distance is determined by formula:

$$d_h = d_{ov} + 0{,}6 \cdot K_1 \sqrt{f + \lambda} - \delta \qquad (2)$$

where: d_h – the distance between nearest conductors of different phases in horizontal position, m

d_{ov} –the minimum gap required on switching surge condition, m

K_1 – the factor depending on ratio between wind "*f*" and *P* - mass loads on conductors as follows.

f/*p*	0,5	1,0	2,0	3,0	5,0	7,0	10,0
K_1	1,09	1,16	1,22	1,25	1,28	1,29	1,30

f – the utmost conductor sag in a span,

δ - correction factor for the distance between conductors, m, for a span between dead-end towers that equals to 0,5m for 110 kV and higher rated voltages,

λ – insulators string length, m.

Application of a V-strings to compact overhead lines of increased capacity allows to limit conductor's movement because of wind load and due to this lessen the distance between phases. Researches showed [5] that an insulator string under maximum wind load has a small sagging even when horizontal load exceeds rated load by 10-20%. In connection with this fact the angle θ of 80-100° between suspension strings secures reliable operation of insulator suspension at maximum wind loads. Insulators string weight increases the stability of conductors on a V-type suspension.

Analysis of a V-type suspension of bundled phase construction and fitting schemes of insulator string showed that a V-type suspension of insulators string is a 4-hinge system. This system under the load becomes equivalent to hard rod system with hinged connection in the points of attachment to the tower crossarm and to the yoke of the supporting clamp. Calculations and experiments on models showed that a 4-hinge V-type suspension becomes movable under wind loads on conductor that are lower than maximum rated loads and rotates phase conductor on angle with relatively small horizontal shift of the phase conductor axes.

Dielectric characteristics of a V-strings [5] are significantly dependent upon the position of insulator string relatively to the geometrical center of bundle and upon the distance from lower insulators to subconductors.

For 500 kV bundles of complex configuration (Fig. 9) the experiments were performed on studying voltage distribution along insulator string. Their goal was to find optimum geometrical dimensions and mutual position of suspension elements. These measurements were made on a full-scale model at the outdoor test installation on the middle and outside phases; they included also so-called chain suspension (Fig. 10).

Studies showed that insulation string length increase over minimum required for 500kV line one in a V-type suspension does not influence the voltage drop observed across the most loaded insulator. Therefore, the string length was not changing during measurements and each string consisted of 22 insulators. Depending on terrain relief the angle *"α"*, i. e. angle of conductor outgoing from supporting clamp, is greatly influencing electrical characteristics of insulating suspension [7].

Measurements of voltage distribution along V-insulator strings for outside phase showed different voltage distribution along its two branches. The outside phase is somewhat asymmetrical relatively the vertical axis. The outmost branch is shielded to some extent by the upper subconductor, and therefore voltage distribution along this branch is more even. The other insulator branch located closer to the middle phase is less screened, therefore the first insulators of this chain have the heaviest load. Main measurements were performed just on this branch of V-string (Fig. 11).

The main results are summarized in Table 2 and on Fig.12. Conclusion from research results was that in V-strings not the distance between the first insulators of two branches influences voltage distribution along the string, but the position of insulator branches relatively the center of bundled phase. With shifting fitting points in a supporting clamp to the center of phase cross-section mass (*h* - decrease) voltage distribution along the chain becomes more even.

Table 2. The maximum voltage drop (kV) across the first insulator of a V- string in outer phase for 500 kV compact OHL

h, m	Angle of conductor convergence, degrees				
	0	5	10	15	25
0,2	20,0	20,3	20,6	21,5	22,1
0,4	21,2	21,8	22,1	23,4	24,2
0,8	24,2	29,9	25,5	26,7	28,2
1,19	28,5	29,7	31,5	33,6	36,4

Particularly, the voltage drop may be reduced by 6.5-7.2% % (20-22 kV) if *h* is lowered to 0.2.

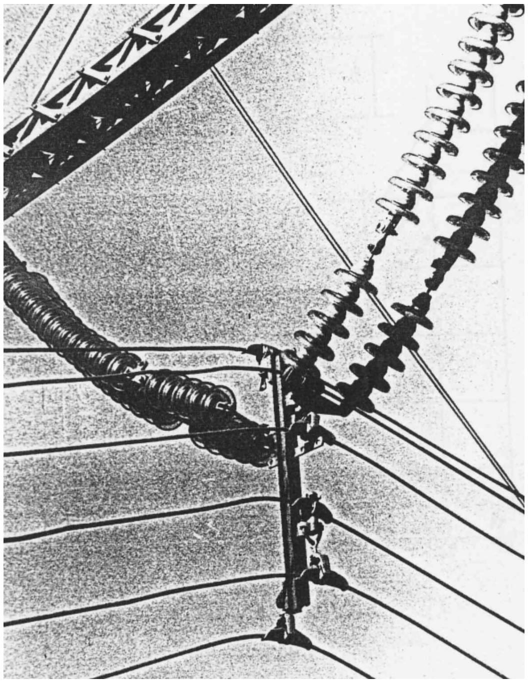


Figure 11. A V-type insulating string for the outmost phase conductor suspension of 500kV overhead line.

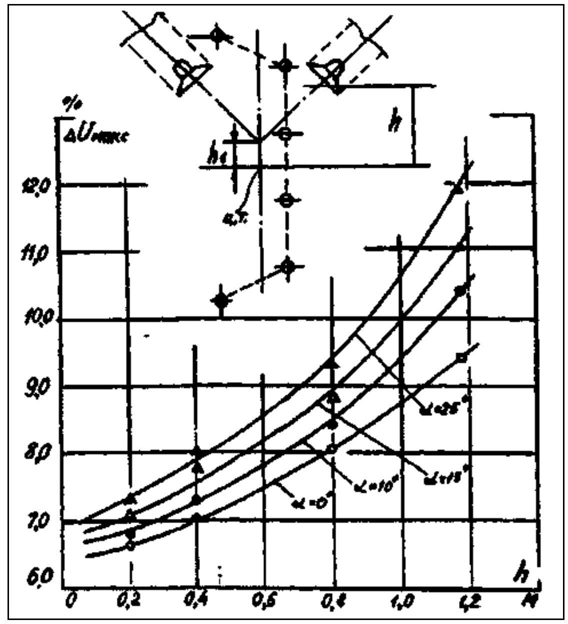


Figure 12. Dependences of maximal voltage drop on the insulators of a single-chain string of the outmost phase on a distance "*h*" with different angles "*α*" of conductor out-going.

With angle *α* (angle of conductor outgoing) increase the electric field gradient significantly rises on upper subconductors, i.e. on the external side of bundle phase curve [7]. *W*ith *h* decrease the influence of angle is also decreasing, as the string is shifting to the conductor zone where angle *α* change has weak influence on gradient of subconductor surface (located nearby the string).

Taking into account load distribution from six steel-aluminum AC 240/32 subconductors of bundled phase within two branches of V-string, a single string of toughtened glass ПС 210-В insulators can be used in each branch or double string of ПС120-В (Fig. 13).

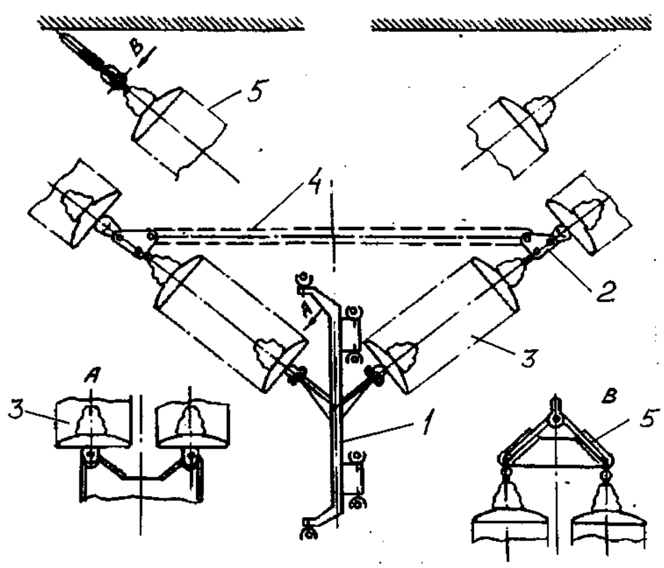


Figure 13. A V-type insulator string for the outmost phase conductor suspension with fittings:

1 - supporting clamp with a conductor,

2- structure insertion with assembly,

3- the lower section of insulating string,

4 - assembling insertion

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Due to high capacitance of glass insulators voltage distribution along the string, especially along two-chain one will be more favorable, resulting in a voltage drop across the first insulator no more than 20 kV.

In case of V-string suspension to the middle of the yoke three of six subconductors of the phase will go through the so-called "window" formed by chain branches. When part of subconductors is going through the "window" the assembling process becomes rather complicated. To lessen these difficulties each insulator branch should be divided into two parts by a special insertion (Fig.13) consisting of ear-ring, ПТМ-type clamp and arbor. The insert serves for fitting temporary assembling string.

At the first stage of assembling the upper ends of insulator string are fixed to the tower, and the middle chain is fixed to temporary assembling string (Fig. 14) to which take-off rolls with conductors are attached. Using this method of assembling, rolling, visual ling and conductor's taking-off to the boats of supporting clamp are performed in the same way as for the free conductor's chain assembling.

After conductors replacing the low sections of string are fixed to support clamp the temporary assembling string is removed. The temporary assembling string, in this case, is also used for lifting of fittings, take-off rolls and supporting clamps. The Inserts are usually left in chains for the future repair works. The influence of metallic insert on voltage distribution along the chain was experimentally studied (Table 3 and Fig. 15). With installed inserts, voltage drop raises mainly on adjacent to the insert insulators from both sides by 20*%,* but it still does not reach maximum levels observed on the first insulator without insert. Position of the insert is determined by vertical *size* of phase in tower zone and by structure of the supporting clamp.

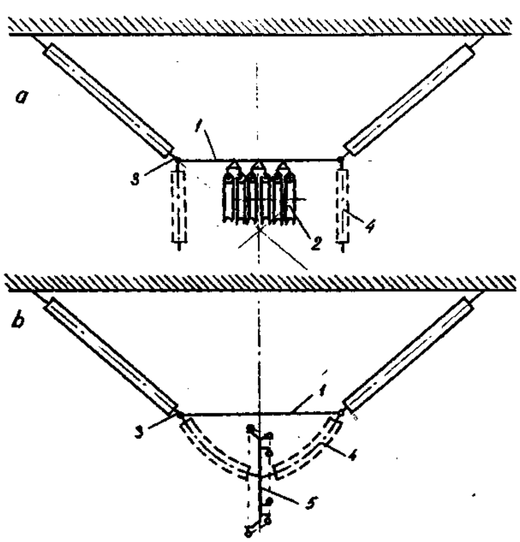


Figure 14. Suspension schemes of assembling rolls and conductor transferring on a V-type insulating string with assembling insertion:

1 - assembling insertion,

2 - set of assembling rolls,

3 - structure insertion with assembling chain PMT,

4 - the lower sections of insulating strings,

5 - supporting clamp with a conductor

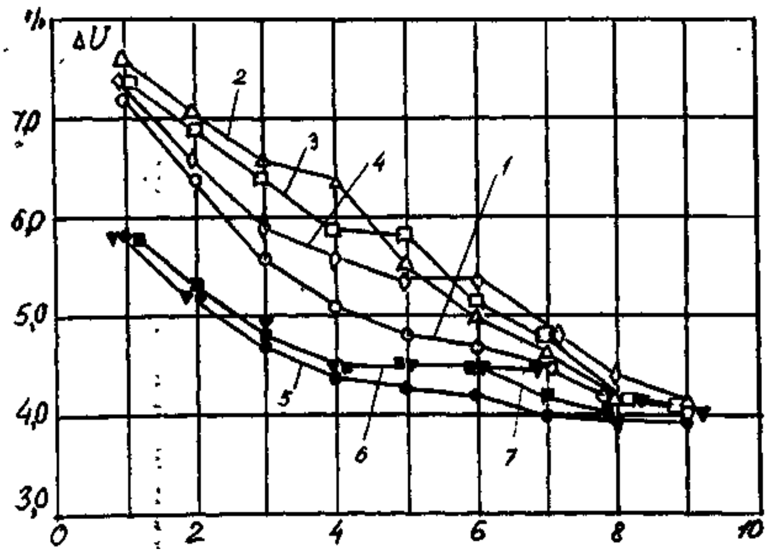


Figure 15. Voltage distribution with α = 0 on the insulators of a two-chain insulating string: 1 - 4 - for the outmost phase conductor, 5 - 7 - for the middle phase conductor;

1, 5 - without insertion,

2 - with insertion between 4th- and 5th insulator,

3, 6 - with insertion between 5th and 6th insulator,

4 - with insertion between 6th and 7th insulator,

7 - with insertion between 7th and 8th insulator

Table 3. The voltage distribution (kV) along insulators near the live end for 500 kV double chain V-string of compact OHL at various positions of an assembly insert.

Set design, insert position		Degree	Insulator number								
			I	2	3	4	5	6	7	8	9
Outer phase	Without an insert	10 25	22,0 23,2	20,0 21,0	17,2 18,7	15,7 16,7	14,8 15,7	14,2 14,8	13,6 13,9	12,4 12,4	12,4 12,4
	An insert between 4 and 5 insulators	10 25	23,5 24,5	22,8 22,4	20,2 20,8	19,7 20,2	17,0 17,8	15,4 15,7	13,0 14,5	12,4 13,0	– –
	An insert between 5 and 6 insulators	10 25	23,0 24,2	21,4 22,0	19,7 20,2	18,2 18,7	15,5 18,2	15,4 17,7	14,5 14,8	12,4 13,0	– –
	An insert between 6 and 7 insulators	10 25	22,6 24,0	21,0 22,8	19,0 20,0	17,5 18,2	17,2 16,6	16,6 16,3	14,5 15,1	13,3 13,6	12,4 12,7
Middle phase, *a* =0	Without an insert	10 25	17,9 18,2	16,0 16,7	14,5 15,1	13,6 14,2	13,3 13,9	16,7 13,3	12,4 13,0	12,4 12,7	12,1 12,4
	An insert between 5 and 6 insulators	10 15	17,9 18,5	16,0 16,7	14,8 15,5	14,2 14,5	14,2 14,8	13,9 14,2	13,0 13,6	12,4 12,7	– –
	An insert between 6 and 7 insulators	10 25	17,9 18,2	15,7 17,0	15,1 15,7	13,9 14,5	14,2 14,5	13,9 14,5	13,9 14,8	13,0 13,6	12,7 13,0

With the insert installed behind the sixth insulator (and after that) the voltage drop observed on the first string insulator is just the same as in strings without inserts. For the ellipse-type bundled phase the distance change between the conductor and insulator strings (Fig.16, distance *a*) influences voltage distribution in the same way as for circular phase configuration [8].

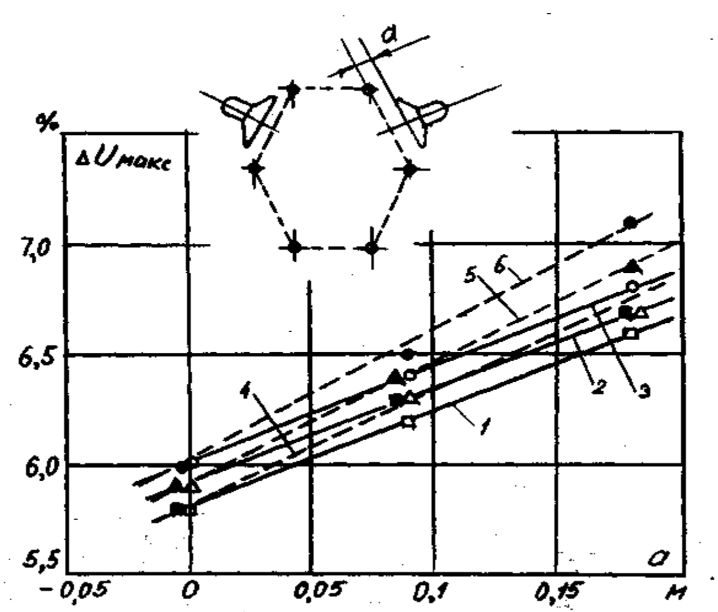
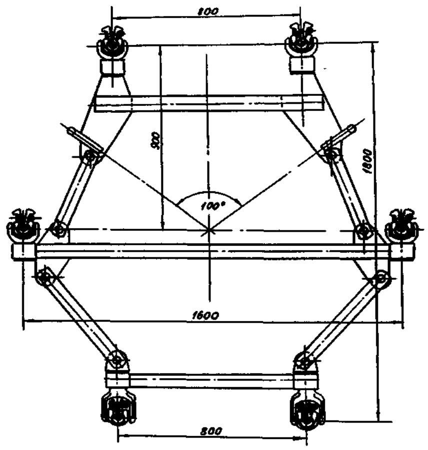


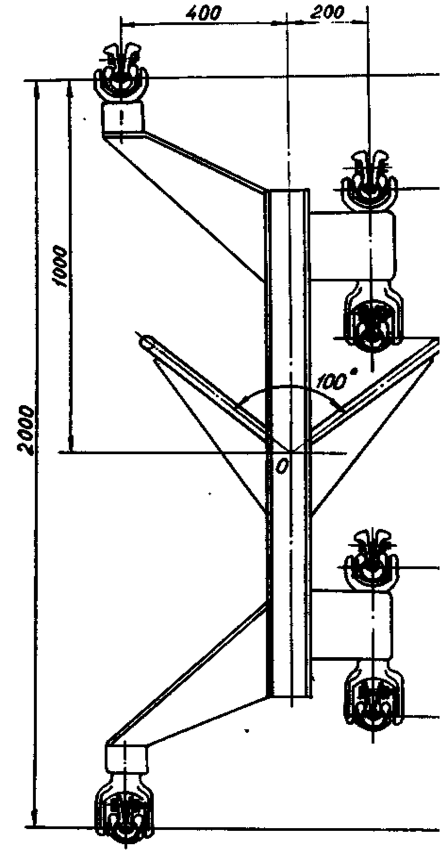
Figure 16. Dependences of maximal voltage drop on the insulator of two-chain insulating string of the middle phase on distance with different angles of *α*: 0° (1.4); 10° (2.5) 25° (3.6) and (1 - 3) - insulating string with insertion between 7th and 8th insulators

The data of Fig 16 prove that with *a*>0 the insertion in the middle phase chain has slight influence on voltage drop at the most loaded insulator. With "*a*" decreasing voltage distribution becomes more even and not depending on angle of conductor outcoming. At "*a*" = 0 insertions do not influence maximum voltage drop of insulator chain (Fig. 16). Therefore while designing V-type suspension of a middle phase it is necessary to achieve $a = 0$, the more so that the phase dimensions and the distance between subconductors allow to meet this requirement.

On the basis of researches results given in this paper supporting: clamps for the outmost and middle phases (Fig.17) for compact 500kV lines with six subconductors per phase bundle were developed.



a



b

Figure 17. Supporting clamp of bundle conductor with oval configuration of subconductors for 500kV compact overhead line:

a - for outmost phase conductor,

b - for middle phase conductor

1.3. Design of commercial insulator sets and line fittings for 500 kV compact OHL, a testing procedure.

This paper section shows the results of further works and research directed toward obtaining final results that will permit conclusive design of a conductor support, insulator strings and line armature for practical use [9].

1.3.1. Design of Insulator Strings.

The designs of bundled outer and center phases with 6 subconductors AC 240/56 differ considerably in size and configuration. Correspondingly the design of the V- insulator strings for their attachment to the suspension towers are also different (see Fig. 18 and 19). The insulator strings for this line were chosen to be of toughened glass. For these supporting strings the insulators ПС120-В were used. There are thirty insulators in each of four chains of the V- string. Each string contains a lower section of seven ПС120-В insulators and an upper section of 23 insulators of the same type separated by a chain of three links with locking armature, and an assembly ring of PTM type. As shown on drawings of Fig. 18 and 19, this string of the armature with construction rings provided a substantial help in stringing conductors with holding clamps, after conductor positioning operation.

The assembly of suspension insulators has no grading rings/horns. To improve voltage distribution along the insulator string, lower insulators are pulled inside the bundle.

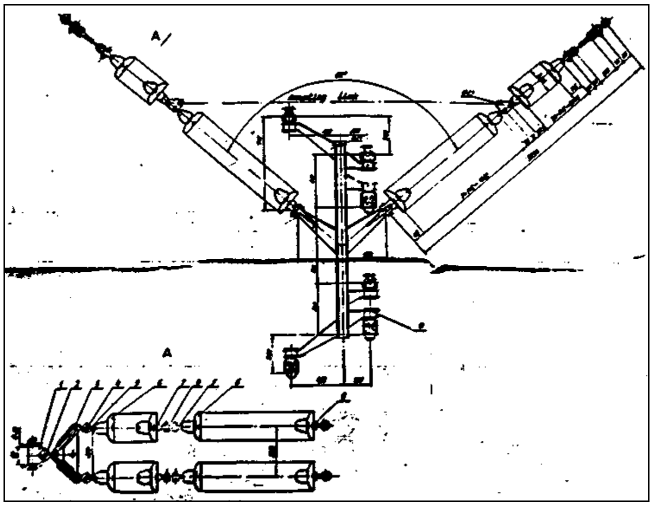


Fig. 18. The Suspension V-shape Insulator String for Attaching the Outer Edge Conductor to the Line Tower

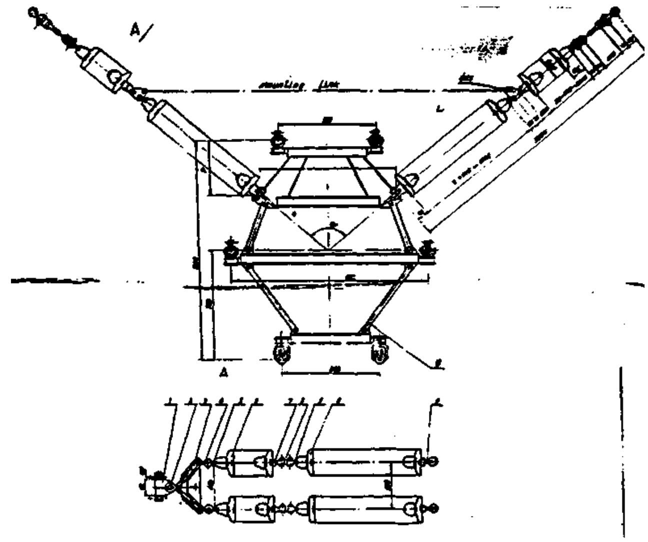


Fig. 19. Suspension V-shape Insulator String for Attaching the Center Phase Conductor to the Line Tower

The dead-end insulator strings comprise of six separately attached strings, each of 27xПС210В insulators (Fig.20). For effective smoothing of the voltage distribution along the insulator string and to limit radio noise, a system of screens made of aluminum pipes, 80 mm in diameter, was recommended (Fig. 21). The conductor attachments are of a general type. When necessary, the suspended conductors are attached to the vertical insulator strings by supporting clamps.

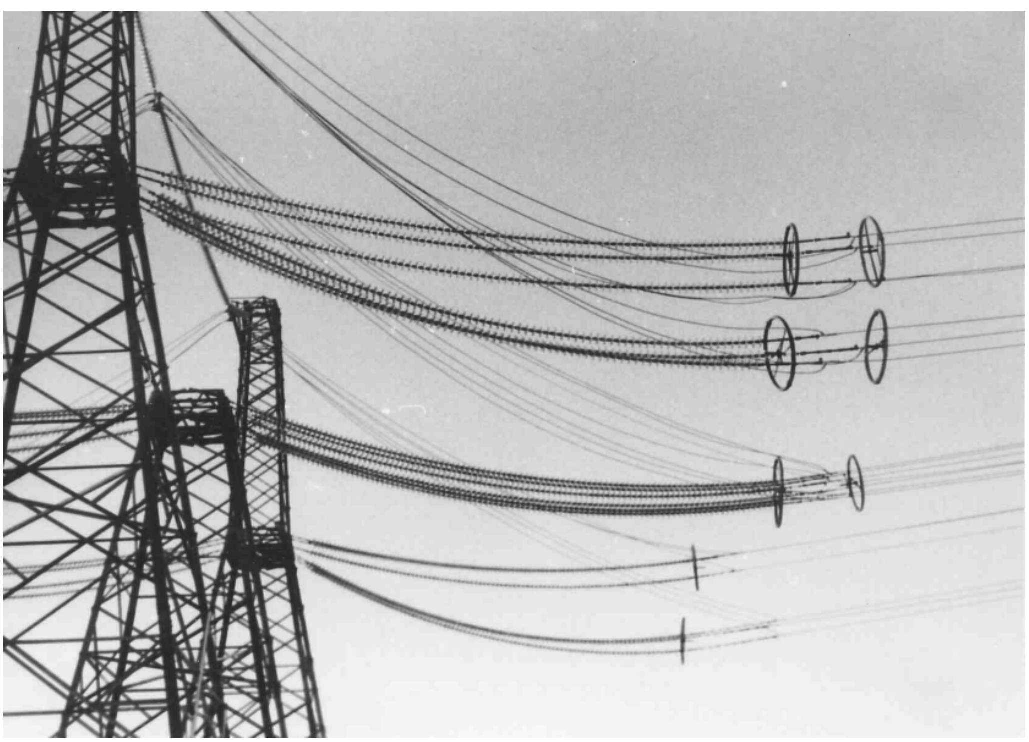
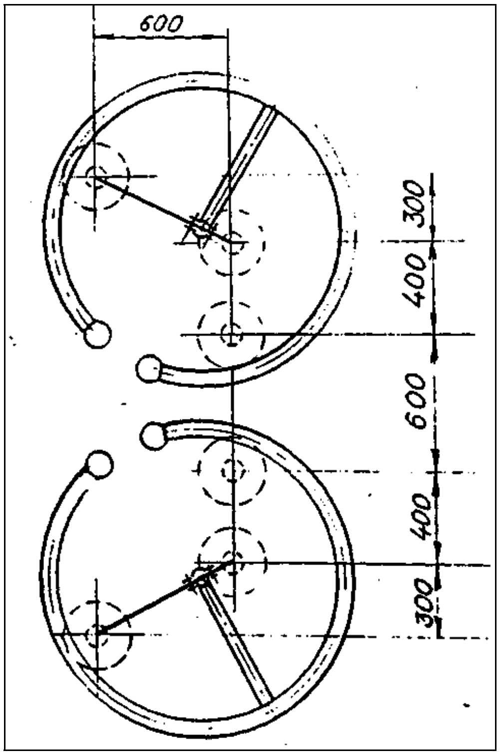
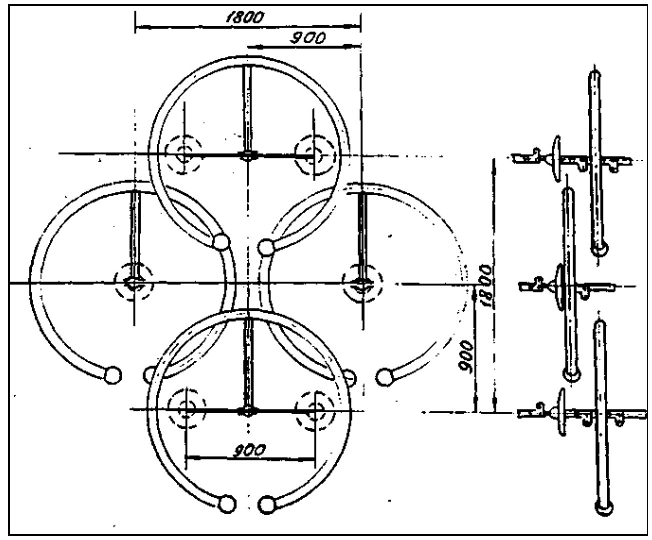


Fig. 20. Suspension Insulator Strings on the Dead-end Tower of the OH 500 kV Compact Test Span in St.-Petersburg



a



b

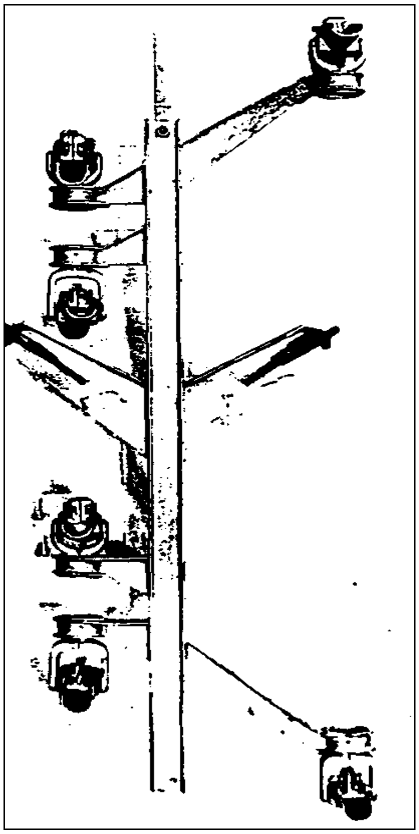
Fig. 21. A System of Protective Screens of a Strain Insulator String

a – for the Attachment of the Outer Phase of Bundle Conductors on a Compact OH 500 kV Dead-end Corner Tower

б – for the Attachment of the Center Phase of Bundle Conductors on a Compact OH 500 kV Dead end Corner Tower

1.3.2. New design of Line Accessories.

The suspension clamps to hold bundle conductors of outer and center phases were developed with utilization of a usual junction positioning drawing boats of PGN type made of aluminum alloy that are manufactured as an open stock. The suspension clamp for bundle conductor of the outer phase made up of б subconductors is assembled with components utilizing the experience of clamp operation on the compact CH 300 kV line at Pskov Gen. Sta. - Novoskol'nik [4]. The clamp is designed for suspending a double V-string with an angle *Θ* between the branches of the string equal 90 to 100 degrees. The point of intersection of branch axes on the V-shaped insulator string coincides with the geometrical center of the bundle phase. The full view of the clamp is shown on Fig. 22. The design of the frame is one-piece, non-flexible. The supporting clamps for suspension of the bundle conductors have a vertical symmetry. The frame of the clamp represents an assembly containing three horizontal girders connected to each other by hinges that operate in conductor pulling. On the upper paired beam are the points of attachments for the V-shaped insulator string. The complete view of the clamp is shown on Fig. 23.



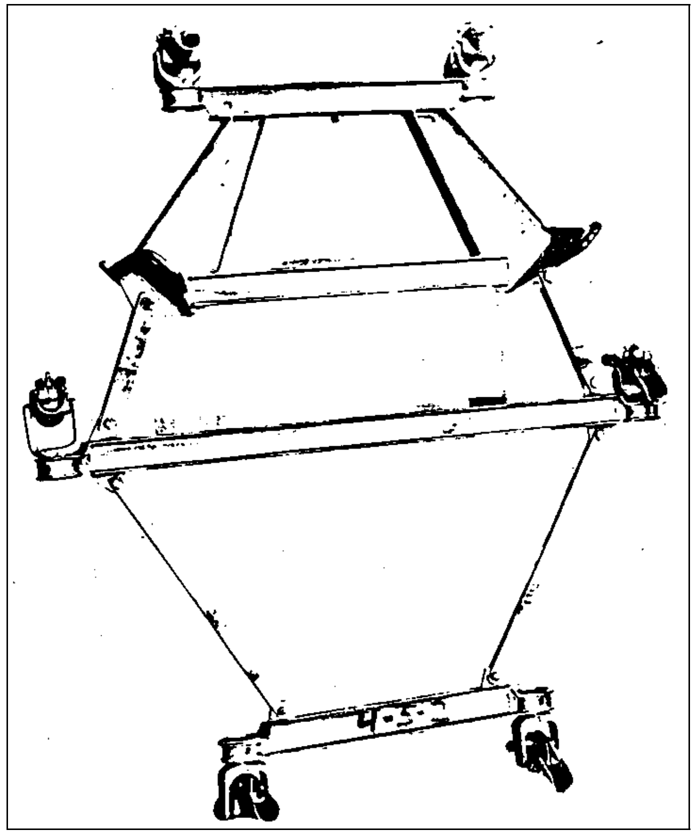


Fig. 22. A Supporting Clamp for the Attachment of the Outer Phase Bundle Conductor with Six AC 240/56 Components to the V-shaped Insulator String on

Fig. 23. A Supporting Clamp for the Attachment of the Center Phase Bundle Conductor with Six AC 240/56 Components to the V-shaped insulator String on the OH 500 kV Compact Transmission Line

The protective screen of toroid form is made of a pipe 80 mm in diameter (Fig. 24). The screen is rigid. For help during mounting, it has a single cantilever angle bracket, and for installation it has a split with screening spherical tips.

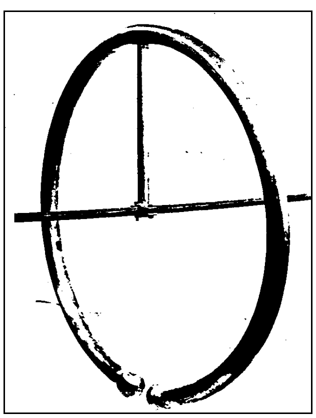


Fig. 24. Protective Screen in the Form of a Toroid for the Strain Insulator Strings of a Compact OH 500 kV Transmission Line

The new technical solution for supporting clamps is the center of the fixed junction for rollers of the suspension drawing boats (Fig. 25). The spreaders for the phase bundle conductors (Fig. 26) were developed on the basis of clamping devices shown on Fig. 25 [4]. The ends of the spreader are thicker and are tightened by a nut into the space between two rubber washers becoming a non damaging rubber/metal elbow joint (Fig. 26) having a thicker body for longitudinal stability when clamped.

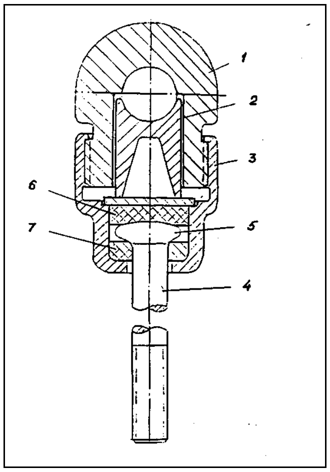


Fig. 25. A Clamp of a Type RGR Spacer of New Construction.

1. Threaded Screen;
2. Movable Spacer;
3. Adapter Nut;
4. Pulling Rod;
5. Pestle;

6, 7. Elastic Rubber Washers

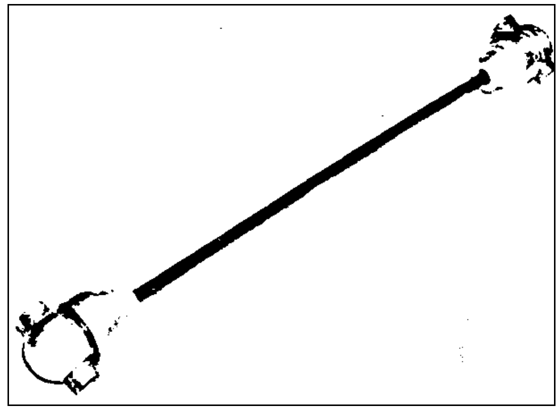


Fig. 26. Dual Spacing Spreader of the RGR Type

1.3.3. The Experimental Research into Insulator Strings and Line Accessories.

During 1991 - 1992 series of experimental operations and studies were conducted for 500 kV compact lines:

- Manufacturing samples of new line accessories and testing their mechanical strength by static loadings.

- Near Alma Ata in Kazakhstan on a wind polygon test site a span of the OH 500 kV line of two phases (the center and one outer phases) was erected to study the non-synchronous vibration of bundle conductors.

- In St.Petersburg (The St. Petersburg Polytechnic University) a test three-phase span of a compact OH 500 kV line was built and the VNIIE conducted direct measurements of radio and television interferences.

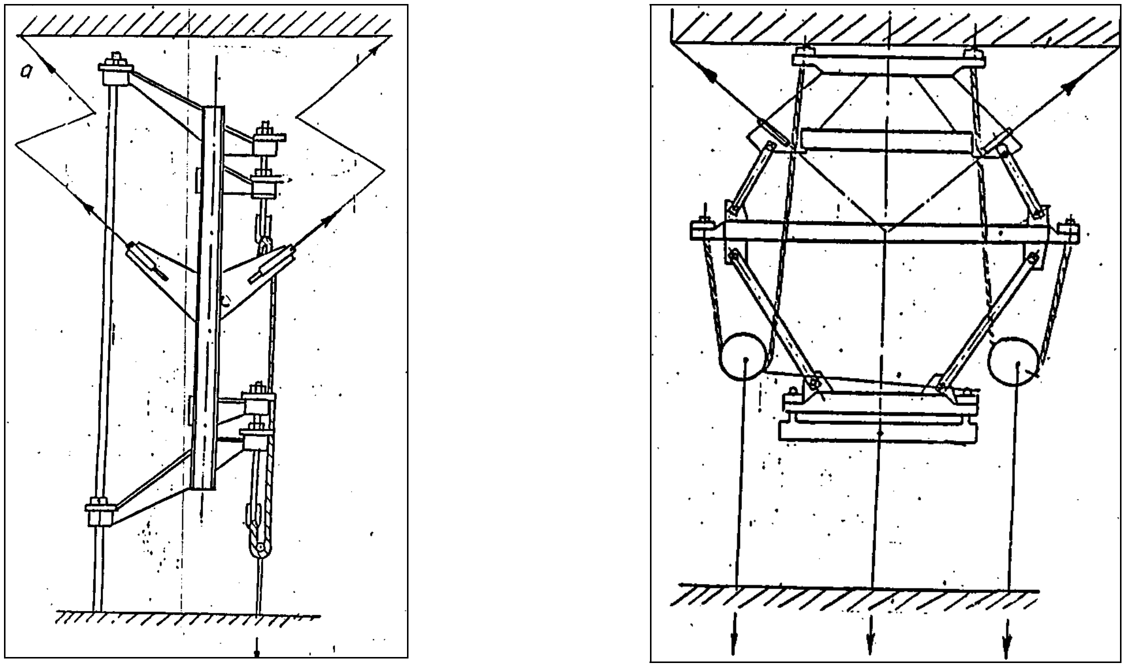
- On a special HV installation the VNIIE conducted measurements of radio interference irradiating from suspension insulator strings of the compact OH 500 kV line.

<u>1.3.3.1 Mechanical Testing Samples for Line Accessories.</u>

New line accessories was tested for mechanical strength to prove they satisfy specification parameters based on related Standards. The tests were conducted with application of static loads in situations similar to ones observed during line operation The clamps were tested at loads higher than specified ones.

The testing of newly developed supporting clamps was conducted on a vertical testing machine with 3000 kN capacity.

The diagrams of load applications to the clamp assemblies are shown on Fig. 27.



a b

Fig. 27. Schematics of the Load Application During Mechanical Tests of Supporting Clamps for a 500 kV Compact OHL:

a – to a clamp for outer phase conductor;

б - to a clamp for middle phase conductor

The tests confirmed that supporting clamps have sufficient mechanical strength. The tests of newly developed RGR spreaders with non-damaging rubber/metal hinges were conducted at VNIIE on test samples. Technically there are two requirements to mechanical strength of spreaders. These have to withstand with no visible residual deformation the following static loadings:

- 1.96 KN (200 kg force) loading applied to any clamp in the plane of the spreader along the centerline of the phase;

- the weight of the conductors when lowering a phase to ground applied to any touching ground clamp, equal to the load weight for the twin spreaders. This amounts to 1.06 kN.

It was planned to standardize the force of clamping the spreader onto the conductor. These tests are conducted usually on a separate clamp of the spreader that is attached to a conductor of the appropriate diameter in order to determine force leading to sliding the clamp over the conductor. The clamp must not move with application of 1.96 kN.

The RGR spreader passed all the tests. The characteristic property of RGR spreaders with rubber/metallic hinge is the ability to deform with resistance in hinges under load moving clamps within hinges to 3-5 degrees with following full restoration of the spreader initial form. The limiting angle of spreader movement to the stopper within the hinge is 12-15 degrees.

<u>1.3.2.2. The Measurements of Radio Interference from Insulator Strings and Line Accessories of the Compact OH 500 kV Line.</u>

The general permissible level of radio interference from EHV lines is standardized by the Standard GOST 22012-82 [10]. Real level of interference from line depends not only on design of bundled phase and line itself, but also on insulator strings and line accessories. The standard on suspension pin-and cap insulators (GOST 27661-88 [11]) limits the permitted RI level to 86 and 60 dB on the 300-Ohm resistance for single insulators used to assemble insulator strings on EHV lines for different classes of voltage, forming flexible insulating construction. The electrical parameters of insulator strings and especially characteristics of RI levels, primarily depend on design of line armatures, the mutual position of bundle conductor and lower insulators of the string and from the shielding armature mounted on the string from both, the high and the low voltage sides.

The RI from the accessories which are part of the insulator string is created by a corona discharges that appear on sharp points and projections of the line armature, or by electrical discharges in the unstable armature contacts. In these cases the limitation of corona discharge on armature can be obtained either by improved design and construction methods and the armature connections, or by utilization of screens of various construction.

The special question is the problem of limiting RI that is caused by electrical discharges on insulators within the insulator string. The interference from insulators can be caused by corona discharges created by local gradients increase through a non-uniform surface of metallic electrodes of the insulators, (for example, on an insulator cap), or by a dry deposit like dry dust or drops of water. In special cases, when there is a defect, such as an air bubble within a cemented part of the insulator, the radio interference can occur by the electrical discharges within those cavities. The source of continuous stable RI from EHV insulator strings is the electrical discharges from the caps and pins of insulators. This refers first of all, to the insulators located within a strong electrical field of a bundled phase.

When the surface of the insulator is dry and clean, then the RI from that insulator is caused by the current impulses from electrical discharges on insulator segments with high gradients. The value of local gradients on insulators, thus the RI levels, depend on the magnitude of voltage across the insulator within the string. This way, the level of RI emanating from the insulator string depends on voltage distribution along its elements. The effective way to level the voltage distribution on an insulator string is to move the lower insulator strings closer to the upper components of the bundle conductor and even to "submerge" the lower insulator between two upper conductors [12].

To measure the RI levels from EHV insulator strings, an outdoor test installation was built at VNIIE. The AC source in this installation was a test transformer manufactured by the TUR factory. The principal electrical setup corresponded to CISPR and GOST 126196-84 [13, 14,15] requirements. A general view of the facility is shown on Fig. 28, 29.

The tests were conducted on double toughened glass insulator V-strings used on the middle and outer phases of the compact 500 kV line. Each branch, contained 30 insulators, as was designated for the Boguchanskaya hydropower plant- Kansk line (see Fig. 18 and 19). The first seven insulators, ПС120А, in each string were separated from the upper part by a mounting armature junction (СП-12-16, РТМ-12-3, УИ-12-16 with combined length of 238 mm). The upper part of the insulator string contained 23 insulators.

*The Measurements of Voltage Distribution Along the V-string. .*Before conducting RI measurements from the insulator strings voltage distribution along the insulator string was measured. The results are shown on Fig. 30. The largest voltage drop was found on the lowest insulator: 6.3 to 8.3% of full potential, i.e. 19.1-25.1 kV at the highest permissible operating voltage applied to the line. The indicated values correspond, respectively, to the outside and inside branches of the outer phase string. For the middle phase string this value was 6.6% (Fig.30, a) or, correspondingly, 20 kV.

These results made on the string with mass produced supporting clamps agreed well with results of tests on mock-up insulator string conducted earlier and described in the Section 1.2 of present paper.

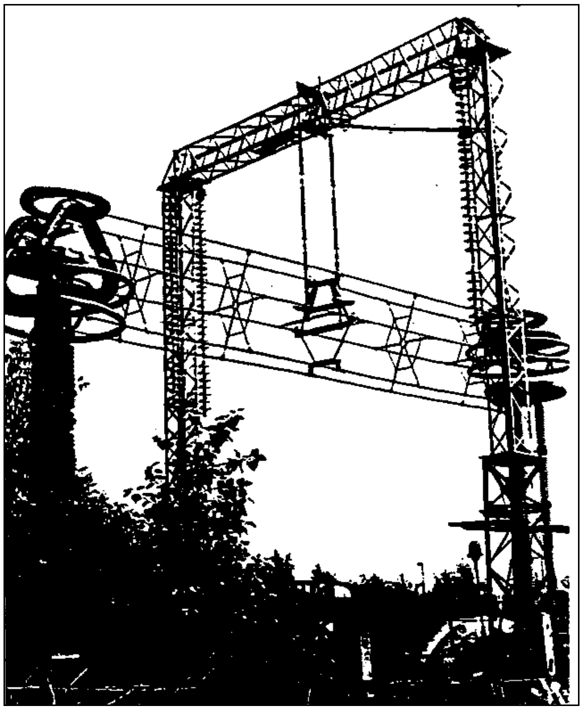


Fig. 28. The Suspension of a Center Phase Model of Conductor Bundle for the Compact OH 500 kV Line from the 750 kV Test Portal on Polymer Insulators

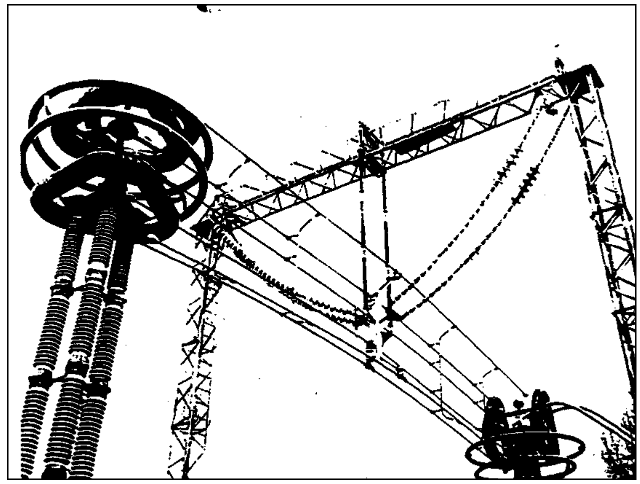


Fig. 29. The Overall View of the V-Shaped Insulator String for Suspension of the Outer Phase Conductors of a 500 kV Compact OH Line on the 750 kV Test Stand

a *b*

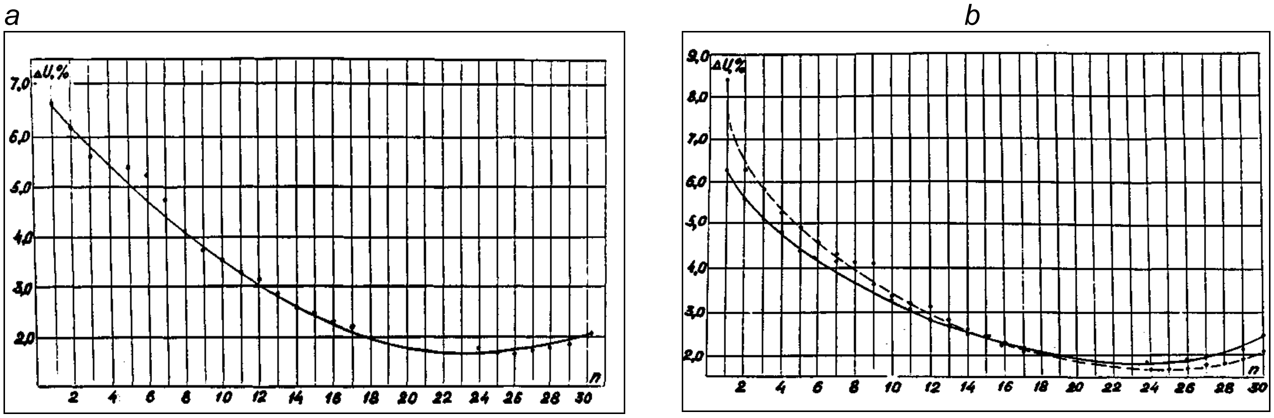


Fig. 30. Potential Distribution on the Insulator String of a V-shaped Assembly

a – for Suspension of a Center Phase Bundle Conductor ;

b – for Suspension of an Outer Phase Bundle Conductor.

1. For the Inside Branch;
2. For the Outside Branch

The RI Measurements on V- String. On the installation for the RI research the mock-up bundles for the middle and outer phases were mounted, each containing 6 components (Fig. 28 & 29). To reproduce the real electric field of the V- string and with the aim of negating interference from the components of the bundled conductors the diameter of the mock-up pipe was accepted to be equal 34 mm. The ends of the bundle conductor mock-up were protected with effective screen system that helped to negate local sources of interference. To obtain reliable results in RI measurements from the insulator strings, special experiments were conducted to determine electrostatic disturbance from mock-up bundle conductors of center and outer phases without insulator strings.

The tests for determining RI levels with such mock-ups of bundled outer and middle phases with supporting clamps were made on two insulator strings. The results of measurements are shown on Fig. 31, 32. The tests showed that in good weather at the highest permissible operating voltage (303 kV L-G), the RI from insulator string did not exceed 41 dB.

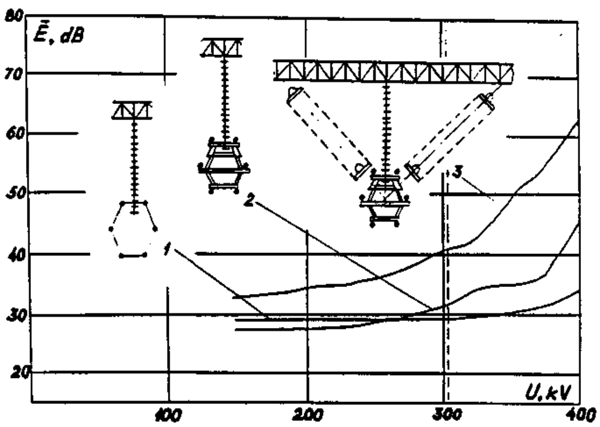


Fig. 31. The Level of Radio Interference Dependence E from Applied Potential U on the V-Shaped Center Phase Insulator String for a Compact OH 500 kV Line:

1 - In the Background a Mock-up of a Bundle conductor is Shown.

2 - The same as 1, but with a Supporting Clamp.

3 - For a V-shaped Insulator String.

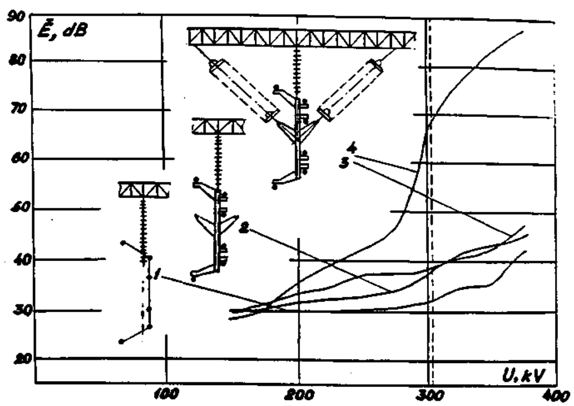


Fig. 32. The Level of Radio Interference Dependence E from Applied Potential U on the V-Shaped Outer Phase Insulator String for a Compact OH 500 kV Line:

1 - In the Background a Mock-up of a Bundle Conductor is Shown.

2 - The Same as 1, but With a Supporting Clamp.

3 - For a V-shaped Insulating String.

4 - The Same, but with Drizzling rain.

V-strings for the outer phase were tested at different weather conditions. The measurements showed (Fig. 32) that the highest RI levels from the insulator strings took place during rain and reached, depending on its intensity, 46 - 68 dB levels, at the highest operating L-G voltage of 303 kV. From data on Fig. 31, 32 and in [16, 17] the conclusion can be reached that the accepted level of RI from insulator strings on the discussed 500 kV line is 45db.

1.3.3.3. RI Measurements of on the Test Span of the Compact 500 kV Line.

The RI research was conducted on the actual test span of the 500 kV compact line erected at St. Petersburg State Polytechnic University that allowed 1- and 3-phase operation. This span was built to the same conductor specification as the 500 kV compact line Boguchinskaya HPP – Kansk. Data obtained from this span indicated that RI level from discussed line does not exceed limits laid by the State standard. In order to fulfill requirements of GOST 22012-82, RI average level at 100 m from the projection of outer phase to ground in good weather for meteorological conditions on the route of 500 kV line Boguchinskaya HPP - Kansk, should not exceed 36.7db. According to tests and computations expected RI the mentioned line will have RI of 35.2 dB.

1.4. Experimental Research on Conductor Wind Dynamics on a Wind Test Installation.

Studies of conductor dynamics was executed at the natural Talapkersky test wind polygon of the Kazakhstan Research Institute near Alma-Ata. This polygon is situated in an area of heavy winds, where a wind velocity above 15 m/s is observed about 50 days in a year. A layout of a compact 500 kV wind span is shown on Fig.33.

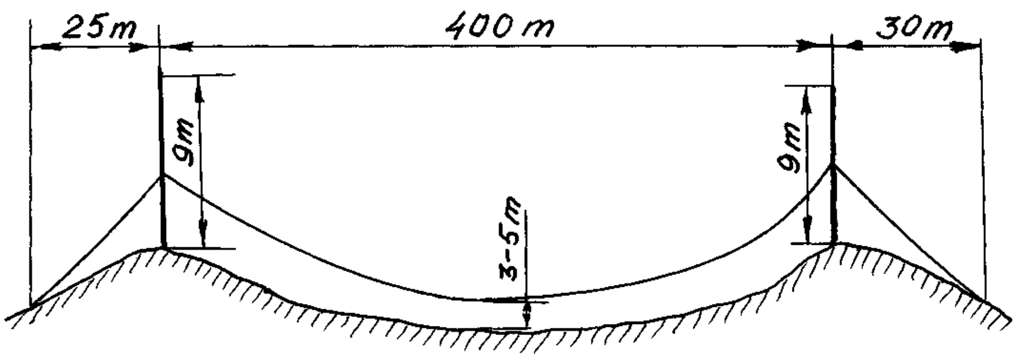
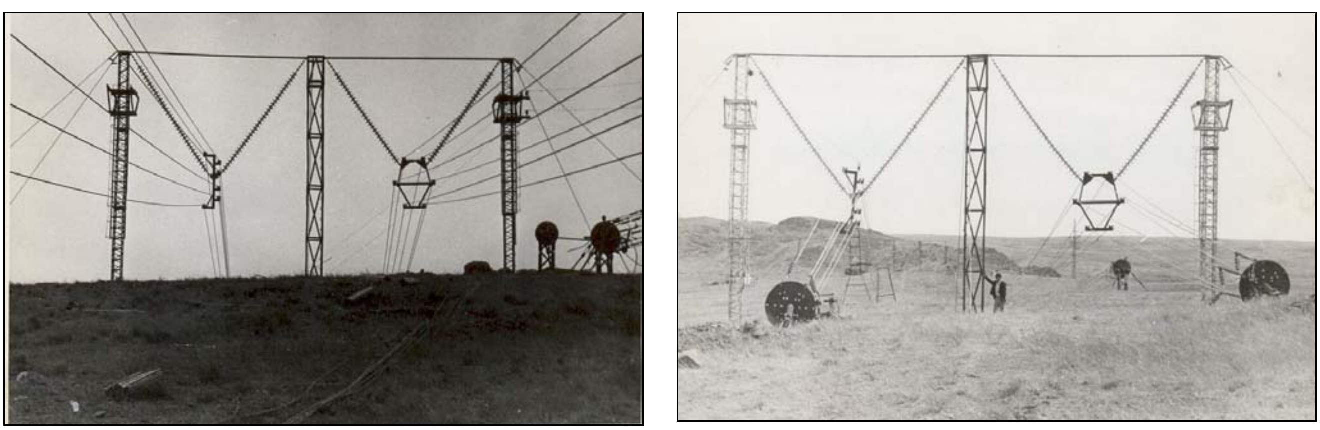


Fig. 33. A scheme of a 500 kV compact OHL wind span

Three phases are suspended at two suspension towers (Fig.34). Phase conductor ends are fastened to anchor foundations buried into the ground by means of steel discs with drilled holes. These holes permit subconductors to be fastened in a variable contour.

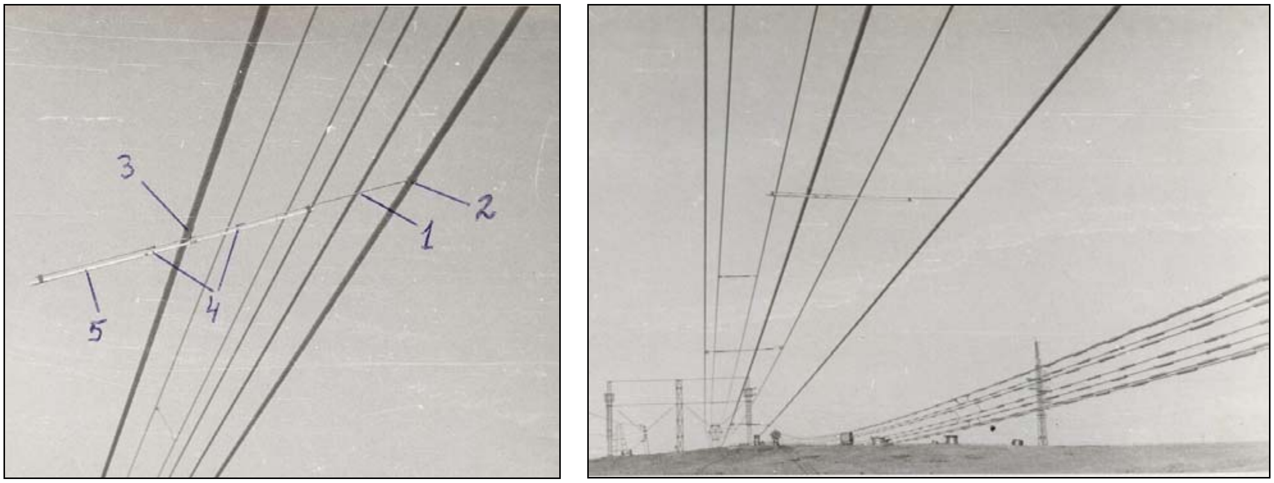


a *b*

Fig.34. Suspension towers of a test span of 500 kV compact OHL

a – north tower, *b* – south tower.

Measurements on a test span was carried out during 1992. The convergence of outer and middle phases was recorded with three measuring devices (Fig. 35) installed at the center of the intermediate 400-m span on upper, center and lower phase conductors.

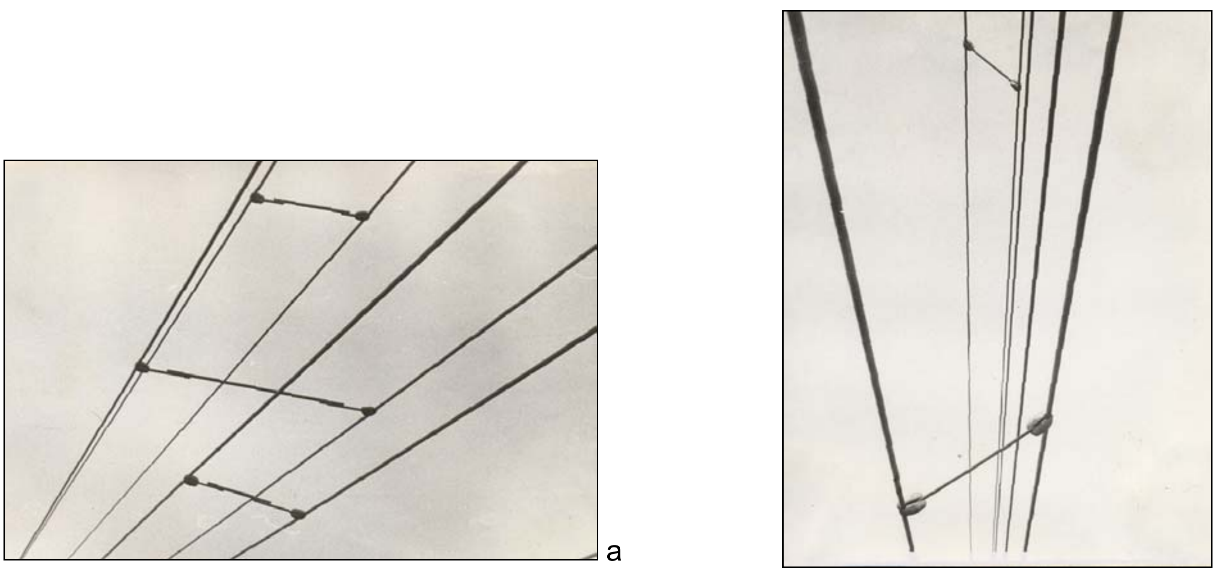


a *b*

Fig. 35. A meter of suboscillations,

a – outer phase, *b* – middle phase

The necessity for three measuring instruments was dictated by the fact that some conductors within phases were free and others were connected with bi-conductor spacers (Fig. 36). As a result, the phases did not behave as a single bundle in which all components would be held together as with traditional design. Therefore, a need arose to observe independent movements of three horizontal pairs of conductors on center phase and single- or doubled pair on outer phase.



a b

Fig. 36. The Spreaders Installation Schematics on Members of Bundle Conductors for the Compact OH 500 kV line during Field Tests on the Test Span.

a - On Conductors of the Center Phase, b - On Conductors of the Outer Phase

During the experiments the maximum convergence between the phases was recorded. These recordings showed that the convergence increases with wind velocity. The most interesting were results for wind speeds 20 to 30 m/sec and higher. Fig 37 presents the correlation between maximum convergence of phases and wind speed directed perpendicularly to the span. These dependencies were collected for upper, center and lower conductors.

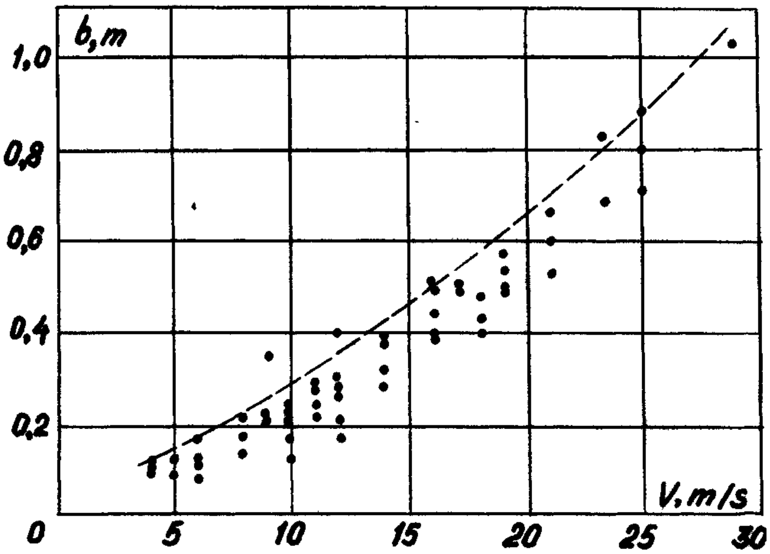


Fig. 37. The Dependency of Maximum Convergence *b* of Center and Outer Phases of Bundle Conductors on 500 kV Compact OH Transmission Line at Various Wind Speeds *V*

From Fig. 37 it evident that with wind velocity of 25 - 30 m/sec., the maximum convergence reaches more that 1m. During the observations no subvibration (the vibration of individual conductors in the bundle) was noted in the middle or outer phases. The stability of conductor supports was not disturbed.

1.5. Design of compact OHLs with taking into account narrowing of its right-of-way and environmental protection

The increase of operating voltage leads to the increase of electrical field gradients under lines up to the values considered as dangerous for people and animals. For this reason it is necessary to find the options in improving line design that provide suitable values of electric field gradients under the line, minimum possible width of right-of-way with increased electric field gradient, as well as necessary limitation of gradient on the conductor surface in order to limit RI and corona losses.

Analysis of electrical field strength under compact OHLs with triangular phase arrangement. When minimum spacing between phase axes and the ground (H_{min}) increases the maximum field strength E_{max} decreases. But in this case the height of towers or their required number increases. In both cases this leads to the increase of tower mass and, respectively, their cost. The decrease of phase-to-phase spacing is more favorable. In this case it is possible to reduce the expenditure of metal for towers. For this reason the decrease in phase spacing is more desirable mean of the limitation of electric field gradient under the line. Unfortunately, the decrease in phase-to-phase spacing leads to the increase in electricl field gradient on conductor surface because of an increase of phase capacitances. For this reason with a minimum number of subconductors in a bundled phase, phase-to-phase spacing cannot be decreased significantly. Respectively, to achieve reduction on phase-to-phase distance one needs to increase the number of subconductors in the phase, or the diameter of subconductors, or both, as well as decrease of K_{ir}. For example, for a 500 kV line with phase spacing D_0=l2 m and with the same distance between all phases and the ground the minimum number of subconductors with the cross-section 300 mm^2 in a phase is three. In order to decrease phase spacing to 8-10 m it is necessary to increase the number of subconductors in a phase up to 4-5 with the same total cross-section. A decrease of the insularity factor K_{ir} can be provided by means of optimization of phase and subconductor positioning in each phase [8]. In this case the distance between the outside phases and the width of area with increased electrical field decreases significantly.

The extremely high electrical strength of air gaps between parallel conductors [10] allows for significant decreasing the phase-to-phase spacing comparing with traditional lines. As a matter of fact, the phase spacing for traditional lines are determined in general by the tower structure, not by the condition of phase-phase dielectric strength. The necessary insulation gaps in order to provide a reliable line operation at switching overvoltages are presented in Table 4, where $K_{ov.s}$ is the rated level of switching overvoltages in p.u. of crest value of operating voltage; S is the necessary length of dielectric air gap and $D_{o.tr}$ is phase-to phase spacing adopted in existing lines. The first column for each operating voltage reflects traditional Russian practice, the second column-achievable result at deeper switching surge limitation.

Table 4. Phase-phase air gap required for overhead lines to withstand switching surges

U_{nom}, kV	220		330		500		750		1150	
$K_{ov.s}$	3	1.6	2.7	1.6	2.5	1.6	2.1	1.6	1.8	1.6
S, m	2.4	1.3	3.1	1.9	4.2	2.7	6.4	3.9	12.1	10.1
$D_{o.tr}$, m	7		9		11		17		24	

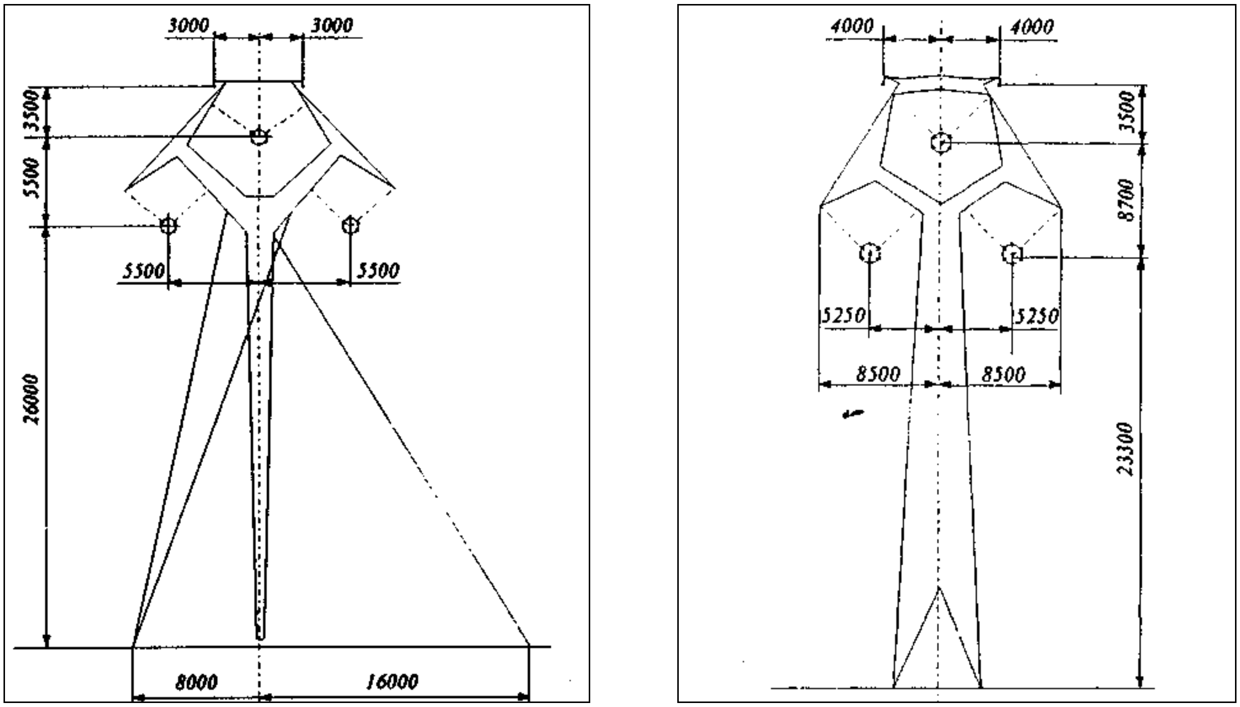
As seen, D_0 and S differ more than by two times, what provides the possibility to decrease significantly phase spacing for overhead lines. Also, for practical application it is necessary to take into consideration the possible decrease of phase spacing under the influence of wind pressure. In accordance with investigation carried out in Russia, it is possible to estimate the maximum possible decrease of phase spacing using data of Fig.37.

Taking into consideration the small probability of simultaneous appearance of maximum wind velocity and maximum switching overvoltages it is possible to use for estimation of possible decrease of phase spacing not the maximum wind velocity, but the specified value $v_{w.r}$=0.4 $v_{w\cdot\max}$. In this case for the span of l_{sp}=500 m and maximum possible wind velocity of $v_{w\cdot\max}$=30 m/s the maximum decrease of phase spacing under the influence of wind pressure will be 0.62 m.

With the aim of narrowing route width where an increased electric field gradient may appear under line conductors a variants of tower structures similar to the widespread "cat" type may be adopted, but with some improvements aimed at decreasing phase spacing, as follows: V-suspension of conductors, and narrowing tower structures between the neighboring phases.. For such application there were developed guyed-type tower and self-supporting tower (Fig.38).

The mass of guyed tower for the 500 kV line with phase of 6x ACSR 300/48, with the span length of 540 m and conductor sag of 19 m is equal only to 7 tons. The mass of self-supporting tower is somewhat higher. In both cases the surge impedance of the 500 kV line is equal to 146 Ohm, the inductive impedance is 0.147 Ohm/km and the natural power is 1800 MW, what is two times higher than for a traditional 500 kV line with phase of 3x ACSR 300/48. When the maximum electric field gradient (on the height of 1.8 m above the ground) is limited by 15 kV/m, as accepted in Russia, for 500 kV lines with towers shown in Fig. 38 the width of an increased strength area is far less than one for traditional line designs, in spite of doubled number of subconductors per phase.

Thus, compact lines of increased capacity may be designed not only with towers of embracing type, but with ones, which are more usual for designers and operating personnel, with only insignificant modification. A high dielectric strength of interphase air gaps was practically recognized. In 1974 in the former USSR the 750 kV line West-Ukrainian substation - Albertirsha (Hungary) was constructed. Some sections of this line have two-leg tangent towers, shown in Fig. 39.



a *b*

Fig.38. Tangent towers for a 500 kV compact overhead line with 6 conductors ACSR 300/48 per phase

a – guyed tower; *b* – rigid tower

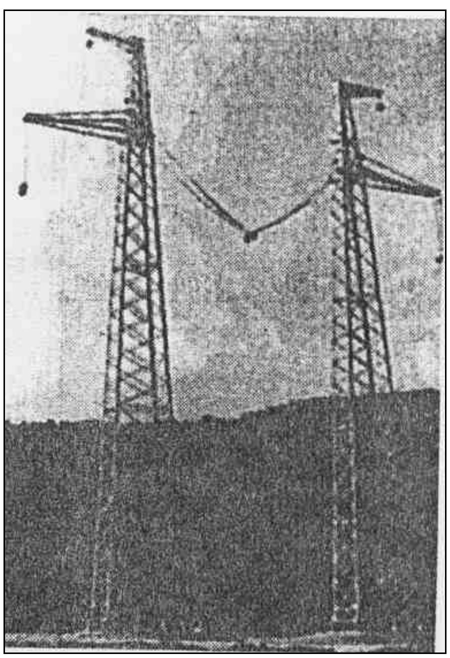


Fig.39. Tangent two legs tower of the 750 kV line "West-Ukrainian substation (the former USSR) -Albertirsha substation" (Hungary)

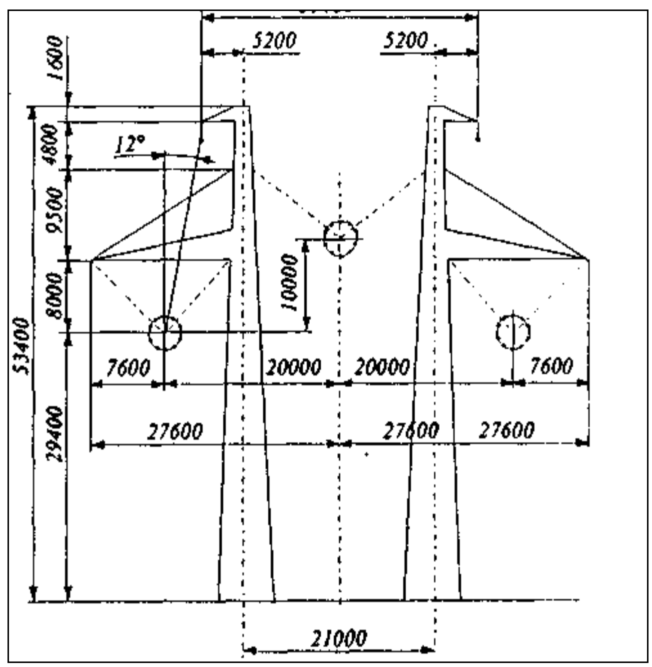


Fig.40. Tangent two legs tower for a 1150 kV compact line

In designing the 1150 kV "Siberia- Ural" transmission the design scheme of the two-leg tangent tower, shown in Fig.6,and based on technical solutions for the 750 kV line tower (Fig. 39) was considered.

The tower has a number of peculiarities bringing the following important advantages in transmission line construction:

- two legs of towers may be alternately placed on their foundations, what permits to use mechanisms which carrying power may be practically half of required to erect a tower intended for attachment of three phases;

- stringing conductor mechanisms may be moved along the line route without any limitation;

- at mounting towers on hill side sections the legs may be placed at different levels, and the position of the middle phase conductor may be freely regulated by changing points of insulator V-set chains attachment to tower legs;

- a tower height may be increased in different sections without essential modifications of tower design by means of a set of "extensions" of a different height.

At the stage of design proposals for the 1150 kV "Siberia - Ural" transmission a tangent guyed tower made according to the scheme shown in Fig.41 has been considered. It is possible to create a 1150 kV line by using tower types presented in Figs. 40, 41, with 10x ACSR 300/48 in phase.

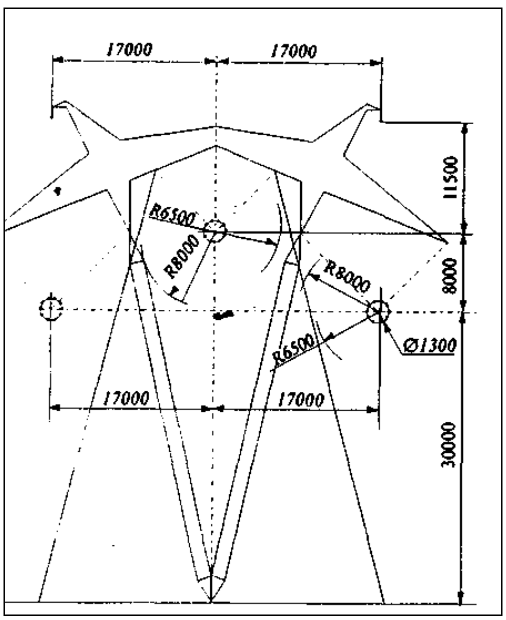


Fig.41. Tangent V-tower for a 1150 kV compact line

At limiting switching overvoltages to 1.6 p.u. the permissible clearance between a conductor and a tower would be S = 5.2 m. Taking a safety margin of 0.8 m an a subconductor radius of 0.4 m the distance of 6.4 m between the phase axis and a tower will be sufficient. On a steel tower structure with the width of 2 m, a phase-to-phase spacing will be 14.8 m. Respectively, a distance between outer phases drops to 20 m (Fig.40). A middle phase is positioned at 10.9 m over outer phases. A surge impedance Z = 204 Ohm; and line natural power P_n = 6770 MW. Compared to the first 1150 kV "Ekibustuz - Kokchetav-Kustanay-Cheliabinsk" transmission erected in the former USSR spacings between outer phases of a compact 1150 kV line could be reduced from 24.3m to 17-20m.

It is necessary to note that in the presence of green plants of a limited height (4-5 m) under the lines the electrical field gradient at their top decreases to the gradient normally observed at the ground level. It is possible to use green plants/fruit gardens of a limited height as shields against the electric field. Special investigation established that electrical field practically does not influence on the vitality green plants, including their productivity. These investigations were confirmed by operation experience of 750 kV lines above fruit gardens in Ukraine.

Table 5 summarizes calculated values of RI in fair weather at 0,5 MHz and at the distance of 100 m from the projection of the outer phase on the ground, E_n and maximum electric field gradient under the line at 1,8 m above the ground, E_{max} for 330, 500 and 1150 kV compact transmission lines with a 4-, 6- and 10-conductor bundle, respectively.

Table 5. Electrical characteristics of compact 330-, 500- and 1150 kV transmission lines

Fig. N	Conductor type	Conductor radius, r_0, cm	Subconductor number per phase, n	Spacing between the outer phases, D_{13},m	Minimum spacing from the phase axis to the ground, H_{min}, m	Maximum electric field strength on the phase conductor surface, $E_{c\ max}$ kV/cm	Radio noise level, E_n, dB	Maximum electric field gradient at 1,8 m above the ground, E_{max}, kV/cm
1	ACSR 150/34	0.875	4	11.0	8.0	29.15	23.5	9.0
2	ACSR 240/56	1.120	6	16.0	8.0	29.50	31.5	13.3
5	ACSR 300/48	1.205	6	10.5	8.0	20.80	19.1	15.0
6	ACSR 300/48	1.205	10	40.0	18.5	25.80	31.0	15.0
7	ACSR 300/48	1.205	10	34.0	18.0	27.30	33.0	15.0

For compact lines it should be given attention to the fact of an influence of tower grounded parts. This effect is especially noticeable for conductors in the middle phase and essentially influences on overall radio noise level.

2. An operating experience of an OHL with an 8-conductor bundled phase

2.0. Introduction

The 1150 kV Barnaul-Ekibastuz-Kokchetav OHL, the first commercial 1150 kV line in the USSR has been developed by the Department of long-distance power transmissions of the Research and Design Institute "Energosetproekt". It was built and placed in operation from 1983 to 1986. In 1983 the first section of the line between the Ekibastuz and Kokchetav substations was energized at the operating voltage.

The main part of the transmission line goes through the North Kazakhstan territory, mainly in a latitude direction. Basically, the 1150 kV line passes through plane territory and is subjected, at individual sections, to heavy winds every year.

Beginning in 1983, yet in the process of the 1150 kV Kokchetav-Kustanay OHL section construction the releasings of V insulator strings were observed. At the first stage these have been considered as accidental ones, created by mounting imperfections (application of M-locks which don't meet specifications for insulator joints). Further, an information stream on damages of insulator strings and line fittings on this line increased.

To find out reasons for damages a more careful analysis of orography conditions for transmission line route and wind conditions, with taking into account design features of insulator sets and line fittings was required.

2.1. Wind regime characteristic of the Kokchetav-Kustanay section of the 1150 kV OHL

The Kokchetav-Kustanay section, 395 km long, was constructed in 1982-1984 in the USSR, on the Kazakhstan territory and placed in operation in 1984. The line has 1090 suspension towers of POG-1150-1 type (Fig.42), 55 angle-tension towers of U-1150-1 type (Fig.43) and 3 transposition towers built by using angle tension towers as the base of design.

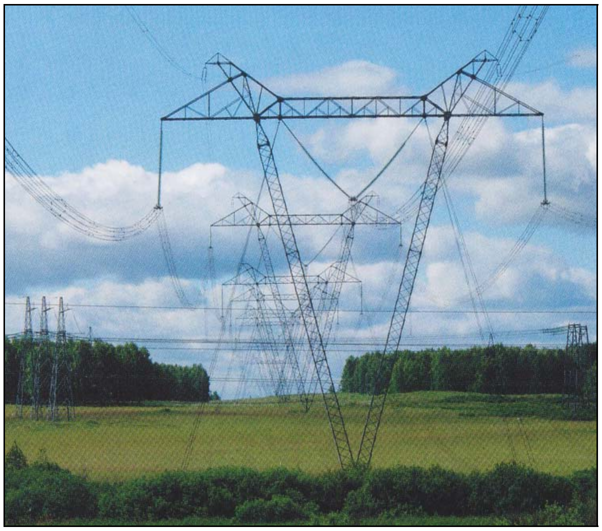


Fig. 42.A section of the 1150 kV OHL with suspension V-sets of POG-1150 type

Fig. 43. A general view of an U-1150 angle-tension tower

Bundled phase consist of eight AC330/43 subconductors. In the section between towers №№ 309-560 a rated wind velocity of 33 m/s has been taken, and between towers NN 560-660 – 30 m/s.

Wind conditions of this region are characterized by information given in Tables 6-8 composed on the basis of data from climatic reference books [21, 22].

Table 6. The probability of wind velocities according to gradations (in per cent of the total case number for year)

Meteoro-logical station	Wind velocities, m/s													
	0-1	2-3	4-5	6-7	8-9	10-11	12-13	14-15	16-17	18-20	21-24	25-28	29-34	35-40
Bologoe	27.8	29.3	23.0	12.1	5.2	1.3	1.0	0.3	0.1	0.005	–	–	–	–
Kustanay	14.0	24.4	26.6	17.0	9.1	3.1	3.2	1.1	1.0	0.5	0.01	0.002	0.002	–
Kokchetav	15.2	19.0	19.5	15.2	10.7	8.1	3.9	2.4	3.8	1.9	0.2	0.1	0.04	0,01

Table 7. The mean number of days with a heavy wind (at velocity of 15 m/s and more)

Meteorological station	Wind velocity, m/s												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	for a year

Bologoe	0.9	0.5	0.7	0.2	0.4	0.2	0.3	0.2	0.4	0.6	0.2	0.3	5
Kustanay	2.6	2.3	3.4	2.6	4.6	2.8	1.8	1.7	2.0	2.6	2.2	2.6	30
Kokchetav	6.6	6.7	8.6	5.9	6.3	4.3	2.7	2.9	4.5	5.1	6.0	6.5	66

Table 8. The probability of heavy winds (m/s) for North Kazakhstan conditions

Meteorological station	Repetition rate: once in…			
	in a year	in 5 years	in 10 years	in 20 years
Kustanay	23	26	27	29
Kokchetav	32	37	39	41

In Tables 6 and 7 the wind data for Kazakhstan are compared with ones for Bologoe that stays in the center of the Russia European part. From data of Table 7, the continuance of heavy winds in the Kokchetav region is seen to be 10 times higher than one in the Russia central region. Fig. 44 compares the probability of heavy wind velocities for Kokchetav and Bologoe.

Data of Tables 6 and 7 reveal that in the probability of wind velocities graded in per cent of the total case number for a year, as well as in a portion of heavy winds in reference to the total case numbers, for North Kazakhstan regions, in comparison with the central European part of Russia are significantly higher. The probability of winds for Kokchetav region is about 100 times higher than one for the Bologoe. Besides, the most dangerous intensive wind impacts on OHLs (at velocities of 20 m/s and more) are absent in the Central part of East Europe.

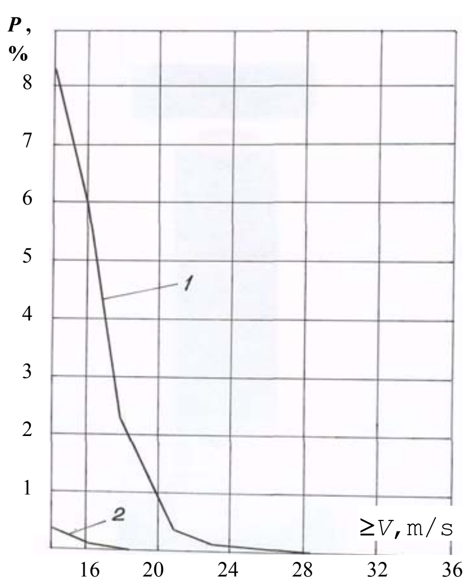


Fig. 44. The probability of heavy wind velocities (in per cent of the total case number for year)

Orographically 1150 kV OHL Kokchetav-Kustanay passes through a plain, the section between Krasnoznamensky settlement and the Sverdlovka town going through Turgayskay valley. The slope of the valley in a southwest direction coincides with the direction of predominant and heavy winds (see Fig. 45 below), so these winds go just across the OHL.

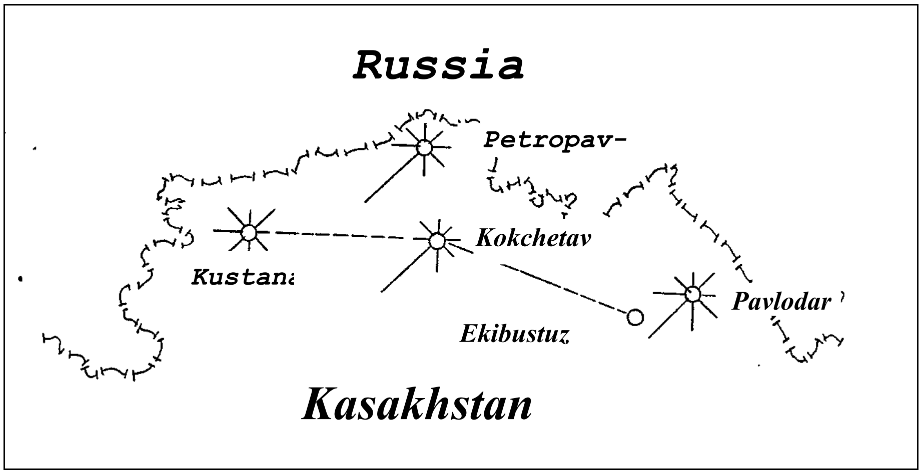


Fig. 45. Wind roses for HMS in the Kazakhstan north part, in regions of the 1150 kV Ekibustuz- Kokchetav- Kustanay OHL route

2.2. Disconnections of suspension set insulator strings

In 1984, on the 1150 kV Kokchetav-Kustanay OHL a disconnection of a PS210B insulator circuit of a middle phase V-set (between 19-th and 20-th insulators counting from the crossarm) was detected. In 1988, a disconnection in the middle part of a PSK-300 insulator circuit of an outer phase double-string took place. Reasons for releasing the insulator strings were impossible to find out. It was supposed that such disconnections were related to wind effects on phase conductors and long insulator strings which didn't occur in practice earlier.

A more detailed investigation of conditions of the 1150 kV Kokchetav-Kustanay OHL route (see scheme in Fig. 46) has shown that insulator disconnections mainly occurred at towers close to crossings of the Tobol River and the Ubagan River valleys.

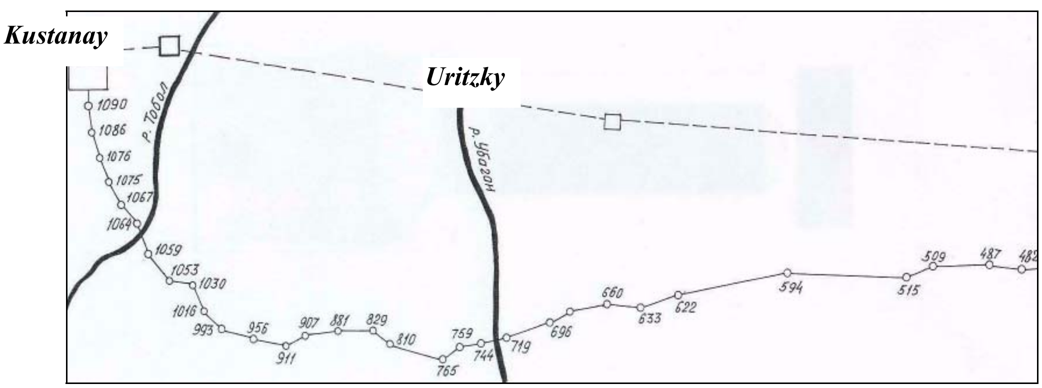


Fig.46. A scheme of the 1150 kV Kokchetav-Kustanay OHL route between towers NN 482-1090. In the scheme numbers of angle-tension towers are given

2.3. Wear of assemblies of insulator set attachment to suspension tower crossarm, breakage of insulators in parallel strings

In 4-5 years after commissioning the Kockchetav-Kustanay line, earlier unknown kinds of damage to insulator sets and line fittings were observed, just on the same part of route where insulator string disconnections were seen.

In 1989 and 1990 a helicopter patrol discovered disconnections of circuits in double V strings on POG-type suspension towers. In March 1989 releasing of left strings of V-sets were detected at towers №№ 706 and 709. Besides, on adjacent towers №№ 704, 705 and 715 insulator breakage in the middle part of double insulator circuits was observed. A climbing-on inspection found also damages and wear of SK-21-1A shackles in KG-21-1 attachment assemblies at towers №№ 709, 710 and 716. It was noted that damages on insulator winward circuits occured more intensively than on leeward circuits.

In 1990, a helicopter patrol detected disconnections of insulator circuits on towers №№ 757 and 771. Releasings of outer phase circuits of 56xPS-300K insulators arose between 41st and 42nd insulators at tower № 771 and between 49th and 50th insulators at tower № 757. The large number of broken insulators was observed in the middle part of V-strings at towers №№ 776, 769, 821, 829, 1026, 1027, and 1029f.

2.3.1. Wear of attachment assemblies of KG type

Fig. 47 shows a design of a double V-string (60x PS210B insulators in each string) attached to the tower crossarm by attachment assemblies of KG-21-1 type.

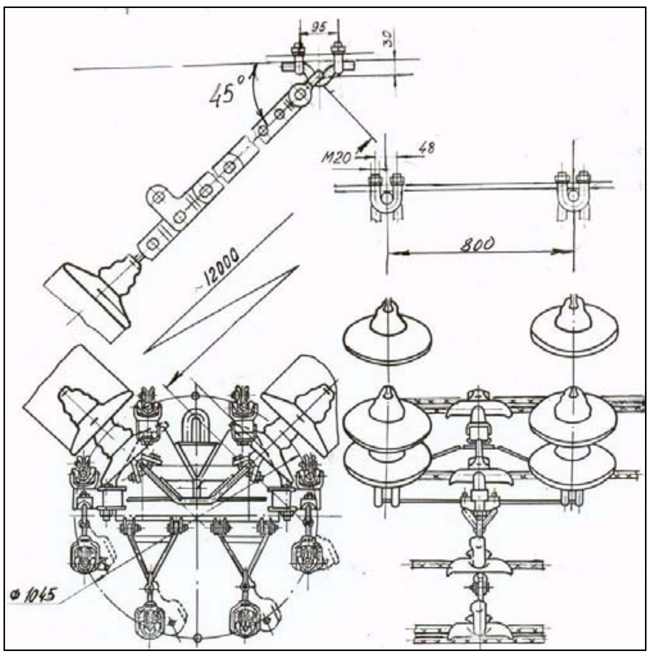


Fig. 47. A V-set for suspension of a middle phase bundled conductor to the crossarm of a suspension tower of POG 1150 type together with attachment assemblies of KG-21-1 type.

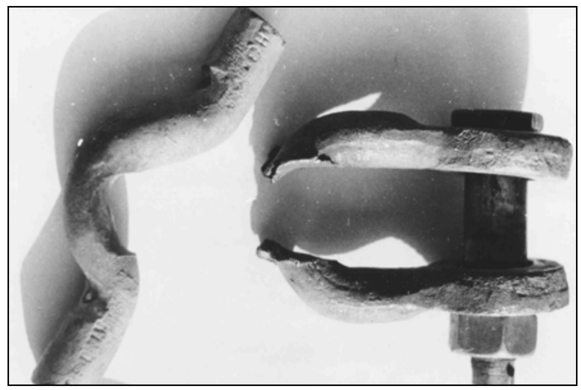
The attachment assembly consists of a small arched beam with a concave middle part immovably fastened to the tower by means of U-bolts, as well as a SK-21-1A shackle connected movably to the small beam middle part. The KG-21-1 attachment assembly operating position on the tower crossarm of POG type is shown in Fig. 48.

Fig. 48. The operating position of an assembly of V-suspension set insulator string attachment to a tower of POG 1150 type.

An angle for applying a load transmitted through the SK-21-1A shackle to the immovable part of the KG-21-1 assembly (the small beam) is about 45° in relation to the tower crossarm horizontal plane. It should be noted, that the attachment of a conductor concentrated mass through a suspension clamp of insulator string to four points on the tower crossarm may results in an unexpected load redistribution between parallel insulator circuits. Such a system is statistically indefinable. Loads between four V insulator circuits may be distributed unequally due to a possible inequality, even small, of insulator circuit lengths originated in production tolerances for insulators and line fittings.

After detection of insulator string disconnections on towers №№ 706 and 709 a climbing-on inspection of towers in the OHL sections closest to the detected damages has been carried out. According to results of the inspection, in addition to replacement of broken insulators, worn SK-21-1A shackles on towers №№ 704, 705 and 717 have been replaced. Partially worn metal parts on towers №№ 709, 710, 716 were also detected in attachment assemblies of I insulator strings of outer phase conductors. Characteristic wear types of details of KG-21-1 attachment assemblies (a SK-21-1A shackle and a small beam) are shown on Fig.49.

a



b

Fig. 49. Characteristic wear of details of attachment assemblies of KG-21-1 type
a – initial stage up to disruption;
b – wear of small beam and complete disruption of a SK-21-1A shackle

Similar wear of details for fastening middle and outer phase insulator strings was found during climbing-on inspections of towers №№621-641. On the section Kustanay-Cheljabinsk the wear of details in KG-21-1 was detected on a tower №1103. Thus, the 1150 kV OHL field experience has shown that wear of details of KG-21-1 attachment assemblies of insulator double circuit suspension strings, both on middle and outer phases, as well as breakage of insulators in middle parts of double V insulator strings produce the most frequent disturbances in OHL operation. These disturbances take place regularly, require considerable maintenance expenses and may result in OHL emergency switching.

2.3.2. A technical solution to improve reliability of insulator string attachment to OHL suspension towers

A load in attachment assemblies of KG type for suspension insulator strings goes through a contact between details with limited surface, practically along the line. At insulator string deflections relative movements of these details under load occur, leading to dry friction wear of junctions. To increase life span of attachment assemblies it was proposed to make the attachment to the tower in a form of a swivel with a design similar to attachment assemblies of KGN type used in insulator sets for long spans of river crossings. Such a design has been developed by VNIIE for suspension towers of the 1150 kV Kokchetav-Kustanay line (Fig.50).

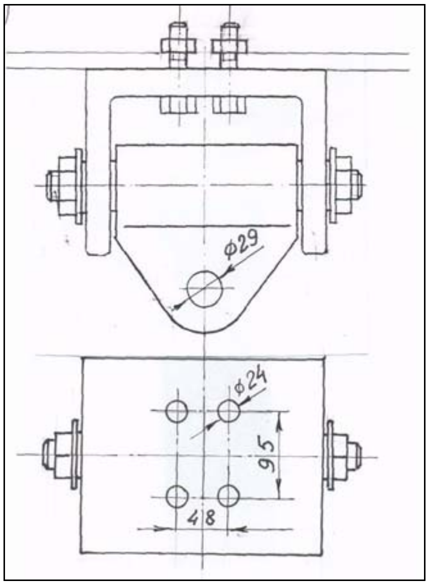


Fig. 50. An attachment assembly of a swivel type developed by VNIIE for reconstruction of suspension insulator set attachment to crossarms of 1150 kV OHL suspension towers

The developed attachment assembly of increased reliability was mounted by means of standard bolts in the place of a deleted KG-21-1 attachment assembly. A contact area of hinge joint shown in Fig. 50 is practically 100 times larger than in of KG-21-1 assembly. Respectively, stresses on contact surfaces are greatly reduced. New attachment assemblies were pr5oduced to the order of a transmission division, and the proper replacement of line assemblies was provided on all phases of the line, first of all at towers crossing the valleys of the rivers Tobol and Ubagan. Further operating experience showed that this technical improvement has solved the problem of wear in suspension insulator string attachment assemblies.

2.3.3. Breakage of insulators in parallel circuits of V insulator suspension strings

As was shown above, breakage of insulators in middle parts of parallel circuits of V suspension strings was frequently observed on 1150 kV line sections subjected to intensive wind impacts (see the scheme on Fig. 46). Undoubtedly, a cause for insulator breakage in parallel circuits was their oscillations with 180° phase shift. Based on the position of broken insulators, these oscillations may be assumed to happen on the first and the second frequencies of free oscillations of insulator strings (Fig.51).

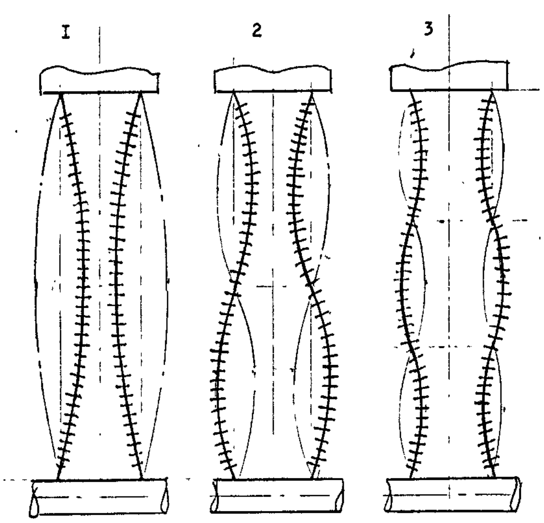


Fig. 51. Probable oscillation modes of parallel strings of a double-string suspension set 1, 2, 3 – at the first, the second and third oscillation free frequencies, respectively

To determine how such oscillations occur the calculations of possible frequencies of oscillations initiated by wind flows and calculations of free frequencies of insulator string oscillations under load have been performed.

To estimate the possibility of insulator string oscillations under wind impact, aerodynamic calculations for a model of an insulator string in the form of a cylinder were made. A diameter of the cylinder is equal to one of the insulator disc. For a PS 210B insulator this diameter is equal to 320 mm and for a PS 210K insulator - 410 mm.

Possible frequencies of force impulses acting on an insulator string in the case of the formation of air whirlwinds are determined by formula:

$$\nu = \frac{1000 \cdot S_t \cdot V}{D} \qquad (3)$$

where: ν – frequency of the formation of air whirlwinds, Hz; V – wind velocity, m/s; D – cylinder diameter, mm; S_t = 0.18 – 0.2 – Struhal number.

Table 9 presents possible whirlwind frequencies on 1150 kV insulator strings at various wind velocities.

Table 9. Frequencies of whirlwind breakaway, Hz, on 1150 kV insulator strings at various wind velocities

Wind velocity, m/s	4-circuit V string with 60x PS 210B (*D*=320 mm) insulators in each circuit	2-circuit vertical I string with 56x PS 210K (*D*=410 mm) insulators in each circuit
5	2.89	2.26
10	5.78	4.51
15	8.67	6.44
20	11.56	9.02

The wind velocities at which resonance oscillations of V-set and vertical set insulator strings are possible can be calculated using the following parameters:

Mass distribution along the insulator circuit are determined based on the initial data on a mass and a pitch of one insulator. For PS 210B insulator mass is 10.8 kg, a pitch is 165 mm, so the linear mass density is $m_{PS\ 210B}$ =10.8/0.165 = 65.45 kg/m;

For PS 210K insulator the mass is 8.8 kg, the pitch is 156 mm and the mass linear density will be $m_{PS\ 210K}$ =8.8/0.156 = 56.41 kg/m.

An oscillation free frequency, ω_n, for a 1150 kV insulator circuit may be estimated with the following formula [23]:

$$\omega_n = \frac{n}{2l}\sqrt{\frac{T}{m}}, \qquad (4)$$

where: n – the number of half-waves in an insulator string length; l – an insulator string length; T – tension stress of an insulator string, N; and m – linear mass density, kg/m.

For insulator circuit of l = 11 m the following possible oscillation frequencies were considered: with one, two and three half-waves per circuit length. Calculated results for strings of PS 210B and PS 210K insulators at line span of 400 m are presented in Table 10.

Table 10. Frequencies of insulator circuit free oscillations, ω_n

Number of harmonic, n	Frequency of free oscillations for insulator circuit, ω_n, Hz	
	PS 210B	PS 210K
1st	0.81	0.96
2nd	1.64	1.94
3rd	2.45	2.90

The comparison of possible frequencies for free oscillations with 1, 2 and 3 half-waves along the circuit (Fig.51) with possible frequencies of whirlwind breakings away (Table.9) demonstrates that the most probable oscillation modes are insulator circuit oscillations at wind velocities of about 5 m/s and with the formation of 2 or 3 half-waves in the span at frequencies of 1.5-3.0 Hz. Under these conditions, insulator string tension stress will differ only slightly as compared with mean operating ones. The load on windward insulator circuit in a V-string increases by no more than 5%, and one on leeward circuit respectively decreases by also about 5%.

In the appearance of conductor galloping a frequency of phase conductor oscillations is close to free frequencies of insulator circuit oscillations. In these conditions conductor galloping may initiate and maintain oscillations of parallel insulator circuits of insulator string. Then, with gradual increase in phase shift until it reaches 180° the collision of insulators in adjacent circuits becomes possible.

As follows from the scheme on Fig. 51, such collision is observed in the middle part of parallel insulator circuits (corresponding to oscillations at the first free frequency) or at distances approximately ¼ and ¾ of an insulator string length (corresponding to the second free frequency), oscillations at the first free frequency having the highest amplitude. According to frequency characteristics of whirlwind breakaways and inherent frequency characteristics of insulator strings as a stressed system, it should be expected the appearance of parallel insulator circuits oscillations at the 1st or 2nd free frequencies as the most probable phenomenon. On the 3rd frequency (Fig. 51) half-wave amplitudes may be relatively small, and insulator impacts with each other in parallel circuits become improbable.

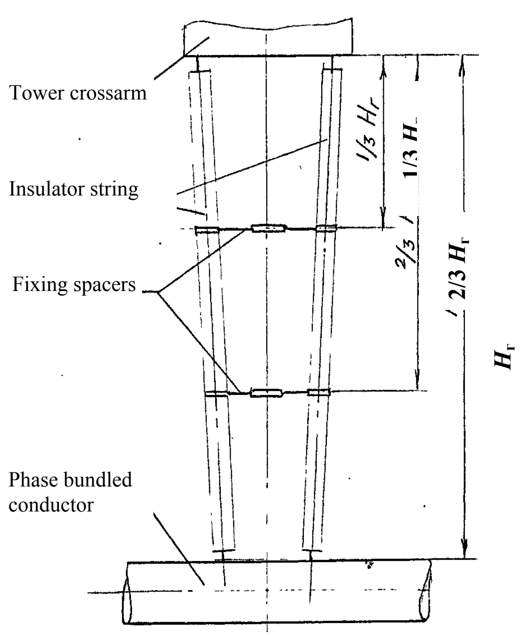


Fig. 52. A scheme of the fixing spacer installation in parallel insulator strings

To prevent possible dangerous forms of parallel insulator circuit oscillations the installation of two fixing spacers was proposed as shown on the above Fig. 52. Here insulator circuits are divided into three sub-spans in which the most dangerous forms of insulator oscillations at free frequencies are limited.

2.3.4. Design of fixing spacers and schemes of their installation in insulator sets

A fixing damping spacer with resin-metal hinges was designed for installation on insulator caps between two parallel insulator circuits of 1150 kV V strings. The spacer (Fig.53) consists of two clamps for fixing on insulator caps and a connecting rod of a regulated length.

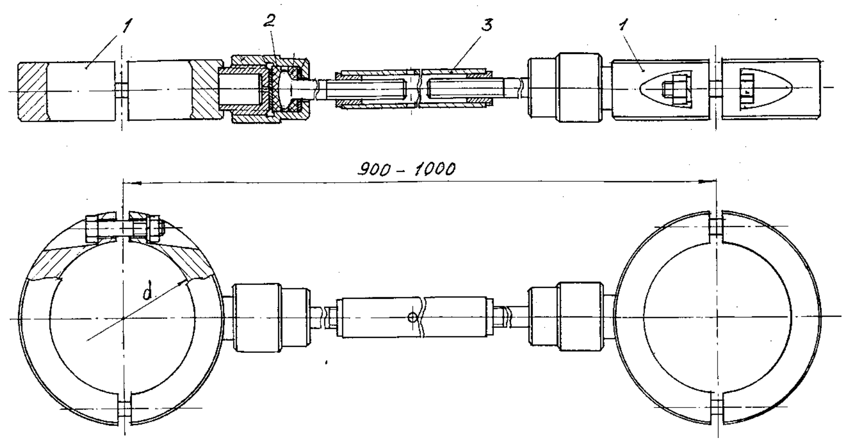


Fig. 53. A fixing spacer-damper with a resin-metal hinge:

1 – half ring;
2 – resin-metal hinge;
3 – turnbuckle

The clamps were made in the form of two half-rings bolted together. In one half-ring there is a nipple with thread for fastening to the connecting rod. The connecting rod fastening to the half-ring was made in the form of an elastic assembly with a resin-metal clearance-free hinge. The connecting rod consists of two pins of 16 mm diameter. At one end of the pins there is a ball conforming to the standard spherical junction and at another end there is M16 thread. Therewith, one pin has the thread of the clockwise direction and another pin – one of the counterclockwise direction.

We recommend to install two spacers per insulator circuit of 11-12 m length, In this case the insulator circuits (Fig. 52) is divided into three approximately equal parts. A length of the bottom spacer is 880 mm and of the top spacer - 950 mm. The installation of spacers in the set may be performed in any sequence.

2.4. Conductor galloping on the 1150 kV OHL

Conductor galloping on 1150 kV line was initiated by winds typical for this the region, especially in the section Kokchetav-Kustanay. At moderate galloping of OHL conductors wear of insulator string attachment assemblies and insulator breakage in parallel strings were forced, as shown above.

In January 1994 intensive conductor galloping took place in the short anchor span between towers №№ 690-696 in the Ubagan river valley. The day before, air temperature drastically increased from –30°C to –12°C, and the process of ice formation on conductors began. With a southwest wind of 6-11 m/s conductor galloping was observed. After switching-off the 1150 kV Kokchetav-Kustanay OHL on December 17, 1994 a team from Kustanay was sent to inspect the line. The team revealed the fall to earth of suspension tower № 695 in the anchor span between towers №№ 690-696 (Fig. 54). The icing of about 15 mm thick was detected on the phase conductors failed to earth. In the adjacent spans continuing conductor galloping with a double amplitude of 3-10 m was observed.

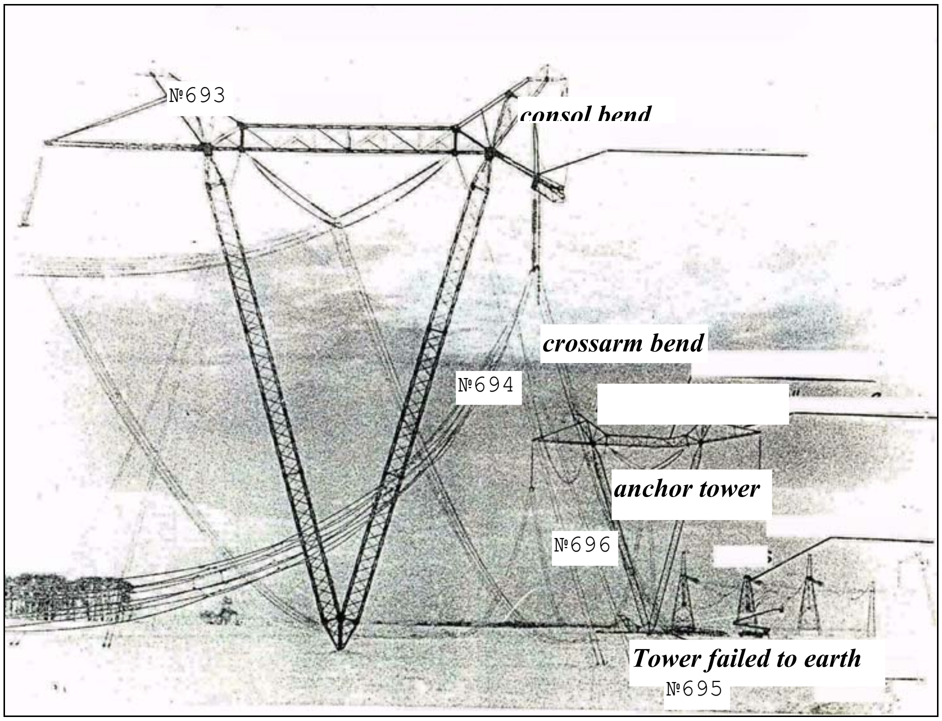


Fig. 54. A view of an emergency section of the 1150 kV Kokchetav- Kustanay.

A detailed inspection of damaged elements and structures has revealed in phase “C” of anchor tower № 696 destruction of two shackles in the KG-30-1 assembly of tension attachment to the anchor tower. The breaking of two PRR-30-1 intermediate links in two remained insulator circuits led to subsequent fall of the phase bundled conductors towards tower № 695.

The design of a 4-string tension set of PS 400A insulator for the 1150 kV OHL is shown in Fig.55.

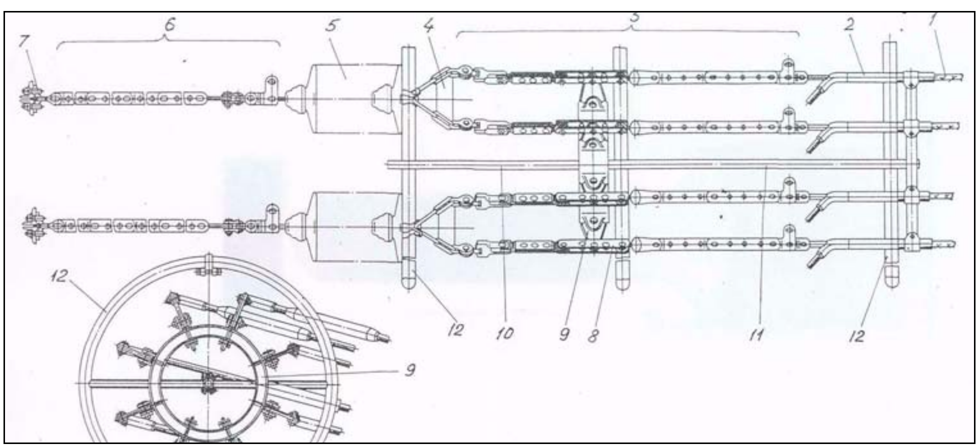


Fig. 55. A 4-string suspension set of PS 400A insulators for the 1150 kV OHL

8 subconductors (1) through tension clamps (2) and a set of coupling fittings (3) are attached in pairs to yokes of 2KU type. A circuit of 41x PS400A insulators (5) is attached to each yoke. In turn, each insulator string through a set of coupling fittings (6) is attached to an attachment assembly of KG-30-1 type (7). An 8-beam yoke (9) (according to the quantity of subconductors) having the beams of limited mobility is fixed on PRR links of a regulated length (8). A shield attachment assembly of UKE type consisting of two tubes with flanges is fixed through the flanges to the 8-beam yoke. The tubes (10, 11) of the shield attachment assembly are welded to the flanges and placed coaxially with the bundled

conductor. Toroidal protective shields of IE-1250-1A type (12) are fixed on the central tubes of the UKE-1200-5 assembly.

Fig.56 shows an assembly of PS 400A insulator attachment to an angle-tension tower leg.

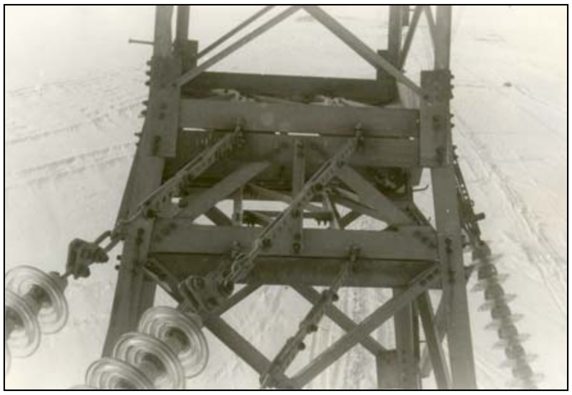


Fig.56. The attachment of PS 400A insulator strings of a suspension set to an angle-tension tower leg with KG-30-1 attachment assemblies

Fig. 57 shows a SK-30-1A shackle with characteristic transverse cracks formed in transverse fluctuating loads produced by conductor galloping.

Fig. 57. The onset of SK-30-1A shackle disruption in conductor galloping. A shackle tongue took an oval form

On exposure to conductor galloping, KG-30-1 assemblies of PS 400A insulator string attachment to towers were subjected to intensive wear (Fig.58).

a

b

Fig. 58. Wear of KG-30-1 attachment assembly details in places of their junction.
A crack resulting in the complete shackle disruption is seen:
a – small beam of hard steel 40x;
b – shackle body of steel 20 with plastic deformation traces

In spite of hinge joint wear in the shackle middle, the shackle disruption took place along the crack in the shackle whole round cross-section (Fig.59).

Fig. 59. Characteristic fracture in the cross-section of a SK-30-1A shackle. Zones of fatigue disruption (1), under bending fluctuating loads (2) and a zone of shackle rupture throughout the residual section are seen.

At conductor galloping, dynamic stresses in insulator strings of a tension set increased to a level exceeding the strength of SK-30-1A shackles. Oval holes (Fig.57) deformed under loads close to the breaking load in the shackle point to that. The cross-section of the broken SK-30-1A shackle shown in Fig.59 indicates that before insulator breaking along the residual section (zone 3) the shackle was subjected to the fluctuating loads, which resulted in forming cracks in the cross-section (zone 1 and 2). The effect of dynamic loads at conductor galloping resulted also in the break of shield attachment assemblies of UKE type (Fig.60) with breaking away of the central tube of the attachment assembly from the flange to the welded joint. A system of toroidal protective shields was deformed (Fig.61), and one of shields broke along the joint (Fig.62).

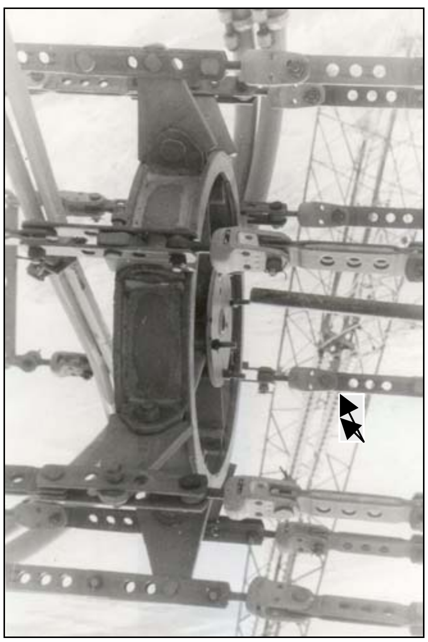


Fig. 60. A radial yoke of 8KL-16-2 type mounted on links of PRR type of a tension insulator set. Fracture places are indicated with pointers.

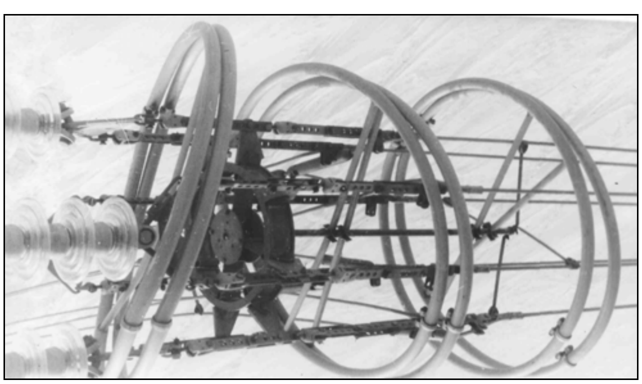


Fig. 61. Deformation of a toroidal protective shield system of a tension set in the action of conductor galloping.

Fig. 62. The effect of dynamic loads on a tension insulator set resulted in deformation and disruption of a protective shield joint (indicated with a pointer).

The initial cause for all damages in the anchor span between towers №№ 209-213 was the disruption of KG-30-1 attachment assemblies. The breaking load of an attachment assembly is 300 kN. In this case it is strange that, according to the project, PS insulator strings attached to this assembly had a guaranteed strength of no less than 400 kN.

The attachment breaking in all tension insulator circuits of the phase “C” led to the turn and then the fall to earth of the suspension tower № 695, to the breaking of eight PGN2-5-19 suspension clamps, to bending of the phase “C” crossarm on the tower № 694, breaking eight PGN2-5-19 suspension clamps in phases “C” and “A”, and bending cross-arm of the tower № 693 in the phase “C”. All conductors of all three phases were damaged in their suspension clamps at towers №№ 692-694.

A helicopter patrolling and climbing-on inspection made later on the section of 1150 kV Kokchetav-Kustanay line experienced galloping revealed, in addition to above mentioned damage, other structural elements failures, among them:

At the tower № 666 the releasing one of the suspension sets of an outer phase because of wrong insulator clip (M3 instead of M24) with the subsequent breaking of the 8PGN2-5-19 clamp body and the fall of the phase conductors to earth.

At the suspension tower № 771 the breaking the 8PGN-2-5-19 suspension clamp in an outer phase and breaking two conductors, the damage of the aluminum layer of other four subconductors and the fall of the phase conductors to earth. At the towers № 770 and N 669 the aluminum layers of two subconductors were damaged.

At angle-tension tower № 690 the disruption of two RG-30-1 shackles in suspension attachment assemblies, similar to tower № 696, but without the disruption of two other residual insulator circuits.

The 1150 kV line Kokchetav-Kustanay on which described disruptions were noted has been designed for wind load per III climatic region (up to 30 m/s) and the presence of ice-sleet deposits for the II climatic region (an ice wall thick up to 10 mm). The possibility of conductor galloping was not taken into account, and preventive measures were not developed.

A suggestion for reconstruction of assemblies of tension set attachment to angle-tension towers

A suggestion developed by VNIIE for reconstruction of assembly of tension set PS 400 insulator string attachment to angle-tension towers, shown in Fig. 63, is similar to the scheme of the KGN attachment assembly reconstruction for assemblies of suspension insulator sets (Fig. 50).

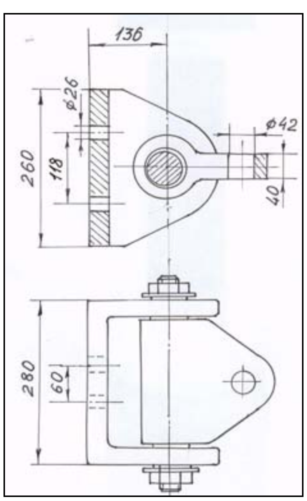


Fig.63. An attachment assembly of RGN type developed by VNIIE for reconstruction of tension insulator sets attachment to cross arms of the 1150 kV OHL

Provision was made for fixation of these assemblies in places of KGN-30-1 attachment assemblies (Fig. 56).

2.5. Wind disruptions of 1150 kV OHL towers

In November 1995 on the 1150 kV Ekibastuz-Barnaul line the disruption of the tower № 212 in the angle-tension span between towers №№ 209-213 and damages of towers №№ 210 and 211 (Fig.64) were revealed. After switching-off of this line other sections of it have been inspected, and a set of other damages have been revealed.

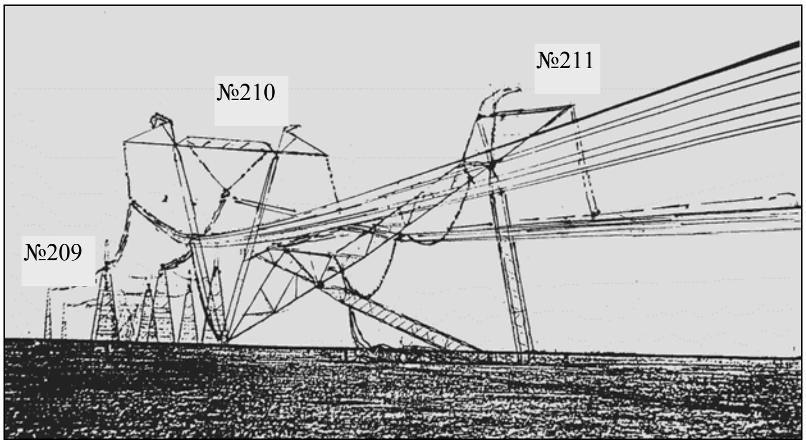


Fig. 64. A general view of towers of anchor span №№209-213 of the 1150 kV Ekibustuz - Barnaul OHL after disruption of tower №212

In the anchor span №№ 153-208 the fall of suspension tower № 200 of POG-1150-5 type and the damage to tower № 201 have been found. According to Ekibastuz weather information, tower disruption and damages in anchor spans №№ 153-208 and №№ 209-213 have taken place under a heavy fitful wind with a velocity up to 35 m/s (at height of 7 m).directed perpendicular to the OHL axis. With height wind velocity raises. Per descriptions received from maintenance staff, tower disruptions were accompanied with bending of main leg angles of the windward leg at a height of 8-12 m from the tower base.

2.6. Data on damages to insulator sets and line fittings as of 1996

Assemblies of insulator attachment to towers, as well as insulator string attachments to suspension clamp tongues are subjected to heavy operating conditions under the heavy wind loads. Heavy winds are typical for climatic conditions of the North Kazakhstan steppe areas. So, according to the reported data, for a period of an autumn-winter maximum of ice-wind loads in 1995-1996 a number of characteristic damages of line fittings and insulators were observed. All the damages took place in the sections passing through Tobol and Ubagan rivers valleys.

Suspension clamps of 8PGN4-5-1 type fastening middle phase conductors to V insulator strings were damaged at 17 towers. Suspension clamps of 8PGN2-5-19 type for fastening outer phase conductors to double I insulator strings were damaged at two towers. The clamps were damaged and had breaks along welded joints and metal parts near places of insulator string fastening to them. Components of hinge joints have traces of wear.

Damages of hinge joints in assemblies of suspension 8PGN4-5-1 clamp two bottom bodies to the clamp yoke, were detected at 11 towers. About 30% of the working cross-section of triangular links, SK-7-1A, SR-7-16 and SRS-7-16 shackles were worn down (Fig.65 and Fig.47).

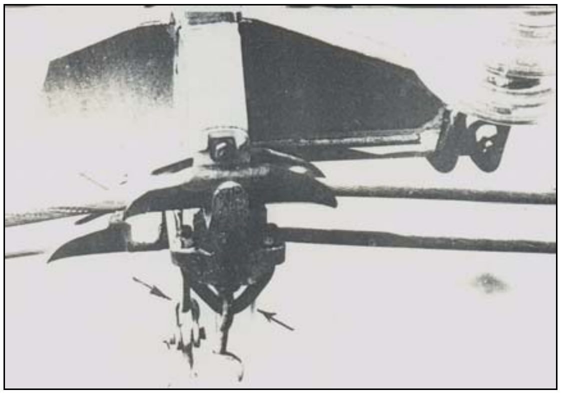


Fig. 65. Wear of hinge joints of 8PGN4-5-1 suspension clamp four bottom clamp bodies in junctions of a SPR-7-16 shackle (indicated with the right pointer) and a SK-7-1A shackle (the left pointer)

Breakage of numerous insulators in parallel circuits of the left string in the middle phase V insulator string were detected at 17 towers in the anchor span between towers №№ 999-1016 and in the section between towers №№ 744-819.

It should be noted, that in dominant heavy winds of the southwest direction the left insulator circuit (running from the Kokchetav) of V-string is windward. In the cases, when the spacers developed by VNIIE have been installed in insulator V strings of a middle phase insulator breakage was not observed, but the spacers were damaged.

One case of SKT-12-1 shackle disruption in ground wire tension fastening to the anchor tower № 993 was also observed.

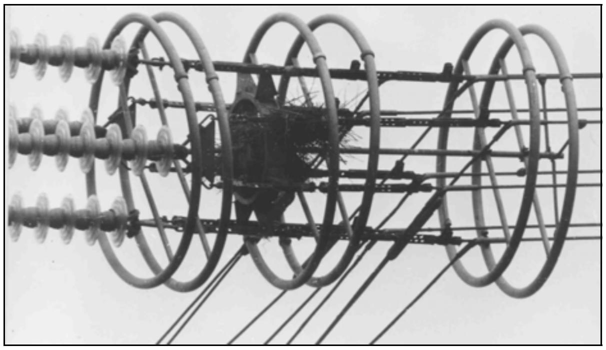
Shield rings were also damaged on 21 tension insulator strings. The shields were made from tubes welded to a round flange fixed to a radial yoke of 8KL type.

In April 1996 on the 1150 kV Kokchetav-Kustanay line the releasing of two insulator circuits on the right side of a middle phase V-string occurred at conductor galloping. The middle phase bundled conductor with a suspension clamp hanging on the residual left circuits executed a pendulous deviation and stroke the tower left leg, which was ruptured after that. Then, the fall and the complete disruption of the suspension tower of POG-1150 occurred.

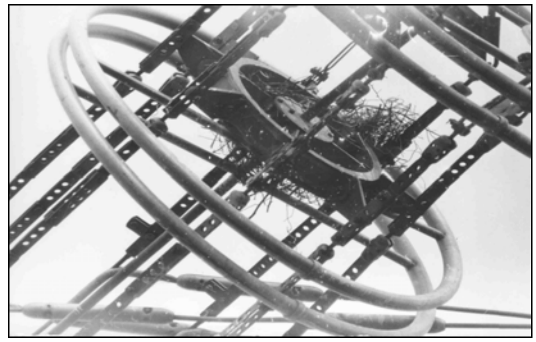
2.7. Radio interference produced by bird nestling on insulator sets of the 1150 kV OHL

In the settlements situated near the 1150 kV Kokchetav-Kustanay line a considerable level of radio interference deteriorated the quality of radio and television reception. In this case, the operation reliability of relay protection, automatics, communication channels, was decreased. A preliminary study of radio interference measurements has shown that a RI source is different from corona on conductors. Its emission had a spectrum different from corona emission and a different law of attenuation with a distance from the line. Although operating at 500 kV, this section of the line had a RI level exceeding one from the line under the full nominal operating voltage.

Inspection searching for the local sources of unusual radio interference gave an unexpected result. A directed antenna found these RI sources on angle-tension towers. The inspection of insulator tension sets with a photoset “Sniper” has shown that bird nests were on the most of tension sets, on line fittings as viewed from the conductor high potential side (Fig.66). Bird nests, mainly nests of crows, consisted of dry grass and aluminum strands chaotically protruding from the nest. Aluminum strands were used in large quantities as temporary bandage bundling during conductor mounting on 1150 kV line, then being scattered along the route. In steppe regions, in the absence of trees dead-end towers have been turned out to be attractive for bird nestling. Neither acoustic noise and vibration nor high gradients of electric field near conductors prevented nesting.



a



b

c

Fig. 66. Bird nestling on 1150 kV OHL suspension insulator sets:
a, b – on fittings of an insulator tension set (on a yoke of 8 KL type)
c – on regulated links of a loop insulator set of a transposition tower

Removing nests from insulator sets eliminated increased local radio interference.

2.8. Conclusion

The wind characteristics of the North Kazakhstan region causes phase conductors and ground wires to oscillate in periods of heavy and long-term winds. Such periods have duration, which is 10-100 times more than one in the Russian Central European part, where most of 330-750 kV lines operate. Under conductor and ground wire oscillations excited by wind, multiple movements in hinges of conjugated details of line fittings take place. First of all, these movements occur in assemblies of insulator string attachments to towers. Wind loads result in an increase of contact stresses in conjugated details working in conditions of dry friction. It results in abrasive wear of line fitting hinge details of hard steel and in plastic deformation of of shackles made of less hard steel. This phenomena of wear of line fitting hinge joints in insulator sets occurred on the 1150 kV line passing through the North Kazakhstan during the first 5 years and got higher intensity than wear of such joints on 500 kV lines in the center of the Russia European part for 40 service years.

Phase conductor galloping periodically occurring on 1150 kV line sections aids in further wear of line fittings hinge joints and results in the occurrence of other damages to insulator set fittings. Therewith, damages and disruptions of yoke constructions of suspension clamps, assemblies of insulator string attachment to towers, assemblies of tension set shield attachment and damages of protective shields take place.

The above mentioned phenomena of wear and damages of line fittings cumulatively increases over time, deteriorate line technical conditions, decreasing its reliability and increasing expenses to operate and repair the line.

Technical improvements developed by VNIIE in designs of assemblies of suspension and tension set attachment to towers, as well as spacers with damping resin-metal hinges for installation in parallel insulator circuits of V strings permit the service reliability of reconstructed insulator sets to be slightly increased. For increasing line service life its radical reconstruction with using more strong and more advanced line fittings of higher safety factors is required. It is also necessary to develop and to install means for limiting conductor galloping on phase conductors, where frequent galloping occurrence have been revealed.

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