HARDWARE AND FITTINGS DESIGN for +- 800kV HVDC Line

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1. Project Background:

At 09:57am, October 26, 2009, the Pole I of ±800kV DC system in the Fengxian Converter Station and the transmission line of the independently designed and constructed Xiangjiaba-Shanghai ±800kV UHV DC Demonstration Project were stepped up to 800kV, indicating the successfully energization of the world's first DC transmission project with the largest capacity, longest distance, most advanced technology and highest voltage.

The project pioneers in the world making breakthroughs in both DC transmission voltage and current, opening a new era for DC transmission technology and setting up a milestone for international power industry. The successful energization of the UHV DC project is of great importance to the buildup of strong and smart grid with UHV transmission grid as the backbone and coordinated development of its subordinate networks. It is a leading innovative project in international DC transmission technology, which will provide important basis for independent development of domestic UHV equipment manufacturing capability and contribute to the energy distribution in ultra-large capacity and ultra-long distance. The success of the project will have great significance and profound influence on the scientific development and innovation of the power industry, the development of major energy bases and large-scale power delivery, the acceleration of clean energy development, and the requirement of the soaring power demand in Eastern China.

The 800kV HVDC transmission line

Hardware fittings installation at river crossing

The test of spacer damper

The inspection for Vibration damper

2. Insulator String and Fittings

2.1 Principle for Selection

2.1.1 Basic Requirements

(1) The configuration of insulator string first should meet the requirements of mechanical strength and electrical strength, mechanical strength is mainly control by the maximum load under normal line working conditions, for electrical strength, it mainly means that the insulator string should not decrease insulation level, and controls the insulator string field strength and should be in conformity with electromagnetic environment standard; secondly, economic cost of various types of strings combinations should be fully considered to ensure the safety, reliability, economy and reasonability of insulator string type design; string configuration should be simplified to the best extend.

(2) Single part weight and size of line fittings should try to reduce to facilitate transportation and installation; It should pay more attention to the ductility of the material when use high strength material to avoid crisp fracture; mature technology, mature material and mature technical processing should be adopted; try best to simplify fittings structure, reduce fittings quantity; the fittings should be with strong exchangeability to facilitate the maintenance to the line; external forces on the fittings should shared evenly and reasonably to meet various load requirements while the line is working.

Spacer should be with good mechanical performance to ensure reliable mechanical strength with reasonable weight, goods damping performance and ability to endure long time fatigue vibration.

The corona free design of the line should satisfy the needs of ensuring insulator working normally under ±800kV voltage, radio interference created should be in conformity with the regulations and requirements specified in GB/T2317.2-2000 Electrical Fittings "Corona and Radio Interference Tests". It must be ensured that no corona will be discharge during the normal working of fittings.

2.1.2 Safety Coefficient

Mechanical strength safety coefficient of the insulator shall be in conformity with Technical Regulations of ±800kV Overhead Power Transmission Lines Design (for discussion), the mechanical strength safety coefficients of the insulator and fittings are as following:

Table 2-1 Safety Coefficient of Insulator and Fittings

	Maximum working load	Line broken	Joint Broken	Normal Load
Disk Insulator	2.7	1.8	1.5	4.0
Fittings	2.5	1.5	1.5	

Note: Composite insulator safety coefficient is supposed to be at 3.0.

2.1.3 Determination of Conductor Average Height and Calculation Base

The average height of the conductor line is defined to be at 28 m for this engineering (corresponding height from the conductor line to the ground is 20 m). The tensile sag calculation of conductor and earth wire are based on the wind velocity at 28 m and 38 m heights respectively.

Table 2-2 Wind Velocity when in Gale and Over Voltage Working Condition

Height		Wind Velocity（m/s）				
10m (base)		27	28	30	32	35
28m	Gale	31.8	33	35.4	37.7	41.3
	Over Voltage	15.9	16.5	17.7	18.8	20.6
38m	Gale	33.4	34.7	37.1	39.6	43.3

2.1.4 Standard Value of Wind Load

Wind pressure uneven coefficient, wind load adjustment of conductor and earth wire, coefficient βc shall be determined according to the following table:

Table 7-2 Wind Pressure Uneven Coefficient α and Conductor and Ground Line Wind Load Adjustment Coefficient βc (10 M from the Ground)

Base Wind Velocity V(m/s)		27≤V<31.5	≥31.5
α	Calculate Tower Load	0.75	0.70
For the calculation of coefficient to a smaller span as jump line etc., it is better to set α at 1.0			

Wind load increasing coefficient of conductor, earth wire and tower shall be considered when in ice covering condition (including uneven ice). Values are to be determined as per the following table:

Table 2-3 Wind Load Increasing Coefficient of Covering Ice Conductor, Earth wires and Tower

Thickness of Covering Ice（mm）	Wind Load Increasing Coefficient of Conductor, Earth wire and Insulator in ice covering condition	
10	1.2	
15	1.3	
20	1.5	
>20	1.5	

2.2 Mechanical Load

Conductor used for the Ice area under 20 mm shall adopt 6×ACSR-720/50, while those under 30 mm is temporarily defined to be 6×AACSR—720/50 steel core aluminum alloy stranded lines. The wind velocity is defined according to the conditions as 10 m high above ground, once 100 years, average 10 minutes' maximum wind velocity which is also the base design base wind velocity is at 27m/s, 28m/s, 30m/s, 32m/s and 35m/s.The designed covering ice includes 10 mm light ice, 15 mm medium ice, 20 mm heavy ice and 30 mm heavy ice etc. Based on tower plan conclusion, the total load of each type of tower is as following:

Table 2-4 Light Ice Area Conductor Insulator String (V String) Load

Tower Type	Shifting Angle Coefficient	V Type String Angle (°)	Comprehensive Load (kN)		Single Leg Load (kN)		Tonnage	Single Leg Joints Number
			K=2.7	K=3	K=2.7	K=3		
Section I（V＝27/28/30 m/s b＝10mm H<1000m）								
Z27101	0.8	90	440	488	343	381	400kN	1
Z27102	0.75	90	499	554	389	432	400(240)kN	1(2)
Z27103	0.7	90	588	653	458	509	240(300)kN	2
Z27104	0.65	90	706	784	548	609	300(400)kN	2
Z27105	0.7	90	824	916	641	713	400kN	2
Z27106	0.7	90	1002	1114	781	867	300kN	3
ZK2710	0.6	90	617	685	477	530	300kN	2
ZJ27101 (3°-12°)	0.7	60/30	590	655	495	549	300kN	2
ZJ27102（12°-20°）	0.7	63/30	717	796	653	725	400kN	2
Section II（V＝32m/s b=10mm H<500m）								
ZV3210-1	0.8	90	381	423	299	332	400kN	1
ZV3210-2	0.75	95	440	489	357	397	400kN	1
ZV3210-3	0.7	95	499	555	423	469	240kN	2
ZV3210-4	0.65	100	559	621	527	585	300kN	2
ZV3210-5	0.65	100	707	785	661	734	400kN	2
ZVF3210-1P	0.8	90	381	423	299	332	400kN	1
ZVF3210-2P	0.75	95	440	489	357	397	400kN	1
ZVF3210-3P	0.7	95	499	555	423	469	240kN	2

ZVK3210-1 (ZVK3210-1P)	0.9	90	588	653	460	511	300kN	2	
ZVK3210-2 (ZVK3210-2P)	0.9	90	558	620	435	484	240(300)kN	2	
ZVK3210-3 (ZVK3210-3P)	0.9	90	528	587	411	457	240kN	2	
ZVJ3210-1 （3°-12°）	0.75	60/40	540	600	533	592	300kN	2	
ZVJ3210-2（12°-20°）	0.75	60/30	624	694	621	690	400kN	2	
Section III（V＝35m/s b＝10mm H<500m）									
ZV3510-1A	0.85	95	351	390	286	317	400kN	1	
ZV3510-2P	0.8	100	440	489	372	414	400(240)kN	1（2）	
ZV3510-3P	0.75	100	499	555	467	519	240(300)kN	2	
ZV3510-4P	0.7	115	559	621	555	617	300(400)kN	2	
ZVK3510-1P	0.9	90	646	718	501	557	300kN	2	
ZVK3510-2P	0.9	90	558	620	432	480	240kN	2	
ZVJ3510-1P （3°-12°）	0.75	60/45	540	600	590	656	300(400)kN	2	
ZVJ3510-2P （12°-20°）	0.75	60/30	624	694	602	669	400kN	2	
Section IV（V＝27/28 m/s b＝15mm H<1000m）									
Z27151	0.75	90	529	588	411	456	240kN	2	
Z27152	0.7	90	602	669	468	520	240(300)kN	2	
Z27153	0.65	90	712	791	552	614	300(400)kN	2	
Z27154	0.7	90	821	913	638	709	400kN	2	
Z27155	0.7	90	931	1035	753	837	400(300)kN	2(3)	

Z27156	0.7	90	1150	1278	928	1031	400kN	3
ZK2715	0.8	90	784	872	606	673	400kN	2
ZJ2715 （3°-12°）	0.75	60/35	694	771	560	622	300(400)kN	2
Section V（V＝30m/s b＝15mm H<1000m）								
Z30151	0.75	90	529	588	467	519	240kN	2
Z30152	0.70	95	602	669	531	590	300kN	2
Z301531	0.65	100	712	791	628	697	400kN	2
Z301532	0.7	95	712	791	662	735	400kN	2
Z30154	0.7	95	821	913	764	849	400(300)kN	2(3)
Z30155	0.7	95	931	1035	869	965	300(400)kN	3
Z30156	0.7	95	1150	1278	1071	1190	400kN	3
ZK3015	0.8	90	784	872	689	766	400kN	2
ZJ3015 （3°-12°）	0.75	60/40	694	771	632	702	400kN	2

Note: 5% increasing of suspension point tension has been considered for tension string load.

Table 2-5 Allowed Vertical Span for Suspension V String in Heavy Ice Area (m)

Number of Strings x Strength		Allowed Vertical Span for Suspension String（m）							Remark
		2×300kN	2×400kN	2×550kN	4×210kN	4×300kN	4×400kN	4×550kN	
String Weight (kg)		3180	3380	3780	5050	6600	7200	8000	
20mm	70°	260	430	640	390	660	990	1420	LH=300
		175	340	550	300	570	900	1325	LH=500
30mm	70°	157	275	430	235	430	670	980	LH=300
		110	200	345	155	350	590	900	LH=500

Note: a. 20 mm ice area adopt conductor of 6×ACSR—720/50 and 30 mm ice area adopt conductor of 6×AACSR-720/50 steel core aluminum alloy stranded lines.

b. Effect of string weight has been considered for the vertical load calculation.

c. Control working condition is ice covering condition.

d. Typical span is 350 m.

2.3 Insulator String Assembly Type in Light Ice Area

Subject to the conclusion of Book IV Volume VI of Study on the Insulator Coordination and Insulator Type Selection, the insulator can be ceramic, glass, composite or post insulator, while disk insulator or composite insulator can be used as suspension insulator in light polluted area, which should be selected according to the weather conditions, working experience and insulator string configuration along the line. Suspension insulators in medium polluted area and severely polluted area are using composite insulators. Disk insulators are applied as tension insulators.

2.3.1 Conductor Suspension String

1) String Type Selection

Normally there are I string and V string for conductor suspension string, V string can reduce conductor spacing and further reduce the tower single base weight, decrease corridor width, lessen house demolition, reduce trees felling and electromagnetic environment impacts, besides, V string is better than I string under same string length, except that the number of insulators is double as that of I string. Upon comprehensive comparison while in consideration of macroeconomic and social benefits, V string arrangement is recommended for suspension insulator string.

In this connection, V type insulator string is recommended to be used as the conductor suspension string in light ice area of this engineering. L type insulator string is recommended for tangent angle tower.

2) V Type String

±800 line has far more a string length than that of a normal 500kV line due to the requirements of insulating configuration, forces on the insulator after being pressured is better than that for 500kV line, the selection of the angle may be different, we have carried out specialized research on this point, which is based on the pressure test research of V type insulator string of 500kV line.

According to the research results of V type insulator string voltage tests by Southwest Electric Power Design Institute and Wuhan High Voltage Research Institute, when the maximum offset angle of windward leg insulator is between 9°～11°, the Insulator pin stress value is related with V type clamp angle, which shows a maximum value when the angle is at 110°and a minimum value at 70°～90°(where the maximum horizontal load is only around 50% as that at 110°). For disk type insulator, when V string angle is at 110°, it is suggested to control the maximum offset angle of the windward leg insulator string within 7°, in the consideration that the safety coefficient of the Insulator pin should not be less than 2.5; for V string with an angle of 90°～70°, the maximum offset angle can add 9°～11°; with consideration of the frequency of voltage, surging effect and electrical clearance reduction etc., the actual angle for insulators controlling during the engineering process is within 5°, which shows no broken or damage of the insulators by far. Based on calculation, V string angle is at 90～100° in light ice area of this engineering.

According to the requirements of the tower load, the maximum single leg joint number of V type string will be 3×300kN and 3×400kN, for some rare towers which are with large load and in need of using single leg three joints (3×300kN or 3×400kN), on one hand, 550kN single leg double joints insulators can be used to meet the engineering requirements, on the other hand, optimize tower position when in construction drawing stage to avoid relatively big vertical span. With the above considerations, it is suggested that the first choice for this engineering should be single leg single joint and double joints strings, single leg triple joints strings shall be reserved. In consideration of the significance of super high voltage line and the properties of the insulator (crisp fracture problem), it is suggested that double joints mode be adopted when using composite insulator for suspension string to ensure the safety of this engineering. Each leg 1×400kN, 2×210kN, 2×300kN, 2×400kN, 2×530kN types of strings are recommended to be used for conductor V type suspension insulator strings in light ice area of this engineering. Each leg 2×240kN , 2×300kN, 2×400kN, 2×550kN types of strings are recommended to be used for V type composite insulator strings.

Refer to the following for single joint and double joints V string arrangements in light ice area:

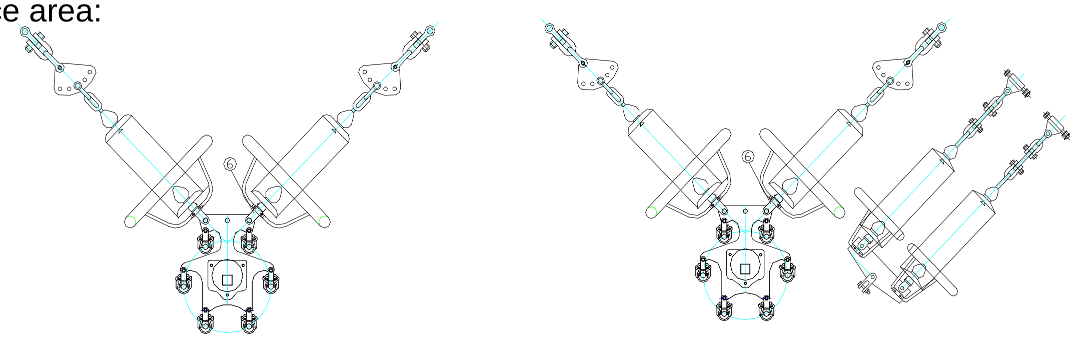


Figure 2-1 Schematic Diagram for Single Joint and Double Joints V String in Light Ice Area

4) L Type String

L type string is used in small tangent angle tower, as per calculation, 2×300kN and 2×400kN combination should be adopted for L type string, the angle of which are 60°+30°, 60°+35°, 60°+40° and 60°+45° respectively, with double hanging points, refer to the following for L type string arrangements:

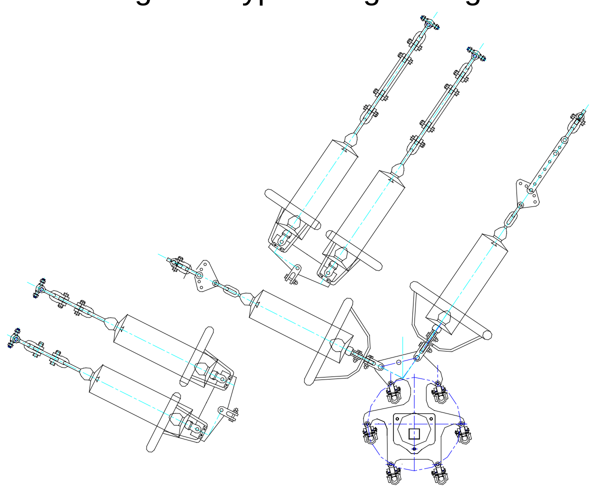


Figure 2-2 Schematic Diagram of L Type String Arrangement in Light Ice Area

2.3.2 Conductor Tension String

1) Tension String Type

The maximum load of tension string in 10 mm ice area is 372.96 kN, tension string insulator strength is required to be 1007kN. While that in 15 mm ice area is 408.52 kN, and a tension string insulator strength of 1103 kN is required. Tension string can be the types as 2×550kN（10mm ice area）, 3×400kN or 4×300kN, the safety coefficients of these type when in broken joints and normal load conditions are in conformity with the regulations.

For the above tension string types, if one hanging point is used, when the fitting connected to the tower is malfunctioning, this is a sign that the malfunction phase conduction connects to ground directly which will cause severe accident, in the consideration of the significance of this engineering and the designing and operation experiences of domestic super high voltage line, independent hanging point for each joint is suggested for double joints and triple joints strings, and double hanging points is suggested for a quadruple tension string. To facilitate maintenance, horizontal arrangement type is suggested for tension strings.

2) Comparison of Tension Strings

Technically, 2×550kN horizontal arrangement tension string is with simple structure, least insulator number, balanced force for each joint, lower accident probability and convenient for maintenance, it is the mature and commonly used tension string type in previous super high voltage power transmission engineering, however, it is with relatively small margin of mechanical strength and restricted working conditions, which means it can only be used in some parts of 10 mm ice area; 3×400kN horizontal arrangement tension string has a more complicated structure than double joints type and a simpler structure than quadruple joints type, with balanced force in each joint, with successful running experiences in the domestic 500kV and large spanning line; 4×300kN horizontal tension string is with the most complicated structure, the most insulator number, higher insulator failure rate and largest maintenance workload.

Economically, 300kN, 400kN, and 550kN are all meeting the requirements of this engineering, set light polluted area for example, the insulator cost for each base tower is as following:

Table 2-6 Tower Insulator Cost

Insulator Strength (kN)	Number of Joints	Number of Insulators	Cost for Each base Tower (10 thousand yuan)
300	4	56	37.63
400	3	64	36.10
550	2	58	39.44

From the above we can see: triple joints 400kN insulator is with competitive price, the issue to be cleared is the influences on the weight of the tower of the three types insulator strings. According to previous experiences, quadruple joints 300kN, triple joints 400kN and double joints 550kN insulator string types are with little influence to the tower weight, price will be the dominant factor, assuming 515 bases for the whole line tension towers, when calculating at a minimum price difference of RMB 15.3 thousand, there will be a saving of RMB 7.88 million for the whole line when using triple joints 400kN type, this is a considerable amount for this engineering, the triple joints 400kN insulator string is with obviously lowest price, quadruple joints 300kN is with a higher price and double joints 550kN, the highest. Above all, the least joints 3×400kN tension string in light ice area is suggested to be the first choice, and 3×400kN, the second choice, 2×550kN (light ice area), the third choice. Refer to the following for the assembly of the first recommendation 3x400kN tension string:

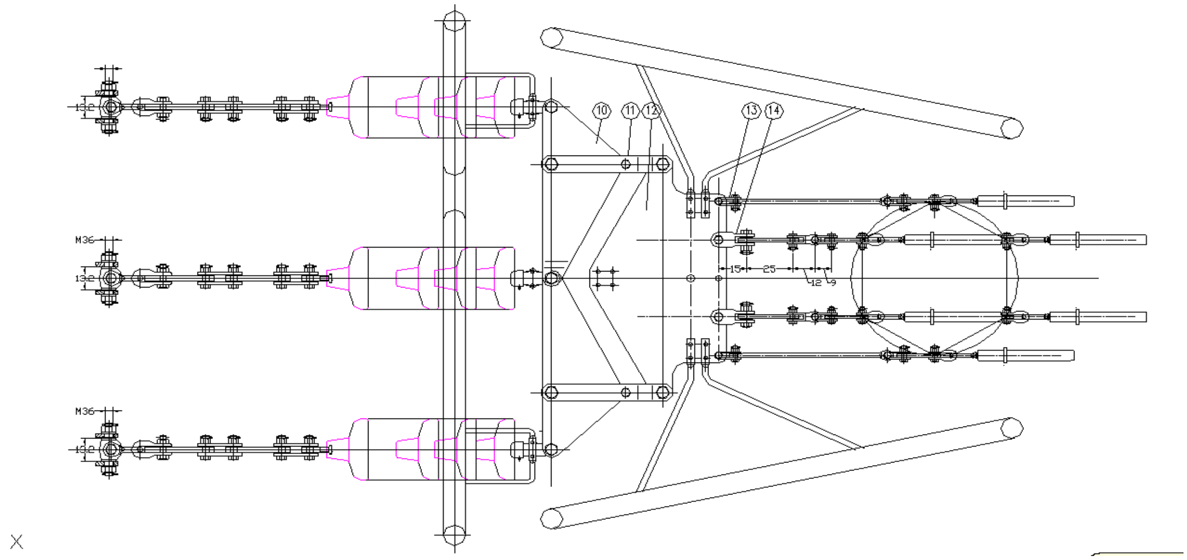


Figure 2-4 Schematic Diagram of Light Ice Conductor 3×400kN Tension String

2.3.3 Joints Spacing

The distance between the strings of multiple joints is determined based on the field strength distribution of the insulator string and the premise of non-contact and non-collision when the insulators between the joints are under working conditions, which means the distance between the joints of the strings is determined by the electrical and mechanical performances of the insulator strings.

For electrical performance, according to the analysis of the pollution voltage test results carried out by science research units for DC double joints insulator strings in high altitude areas, when SDD/ESDD is under a working condition of 0.05mg/cm^2 and the net spacing of dual joints parallel strings of bell type insulators is large than 200 mm, the discharging can be developed independently, but flashover probability is increased, therefore the pollution flashover voltage of dual joints parallel strings is lower than that of single joint strings, when the net spacing of dual joints strings is at 200 mm and 500 mm respectively, the pollution flashover voltage is 2.03% and 5.08% lower respectively than that of single joint strings. Under a salt concentration of 0.10 mg/cm^2, when the net spacing of dual joints parallel strings is at 500 mm, the discharging can be developed independently, the pollution flashover voltage of dual joints parallel strings is 3.9% higher than that of single joint strings, which indicates a little difference between the pollution flashover voltages of dual joint parallel strings and the single joint strings. When in heavy ice, smaller joints spacing will cause the filling up of the clearance between the joints by ice, which will bridge the insulators and decrease ice cover voltage of the insulator, in this case, it is necessary to enlarge the joints spacing to improve electrical performance.

For mechanical performance, as ±800kV insulating string is longer, when determining the spacing between the joints, not only the disk diameter of the insulator, but also the shifting of insulator strings due to wind load function should be considered. After calculation, the maximum shifting is about 24 mm, together with the disk diameter of 400 mm, the total joints spacing should not be less than 424 mm. If the spacing is more than the above value, it can be ensured that there will be no collision of insulators under such an assembly.

The determination of joints spacing should be carried out on the premise that the mechanical performance can satisfy a safety working, while with the control condition that the pollution flashover voltage of double joints structure is not less than that of the single joint structure; for the 400 mm large insulator used in this engineering, it is considered that 20 cm net spacing between the joints can satisfy the requirements for pollution flashover voltage; it is suggested that a basic spacing of 650 mm be used for suspension insulator strings and tension insulator strings.

It is suggested that the science research units to carry out tests of joints spacing to verify the relationship between the pollution flashover voltage of double joints structure and that of single joint structure.

Refer to the following for the recommended values of the joints spacing for multiple joints insulator strings in this engineering.

Table 2-7 Recommended Values of the Conductor Joints Spacing

Ice Area	Suspension String	Tension String
Light Ice Area	650mm	650mm

2.4 Insulator String Assembly Type in Heavy Ice Area

According to the conclusion in Technical Research of Heavy Ice Area Line Design, disk insulator should be used in heavy ice area.

2.4.1 Conductor Suspension String

As per calculation, tower weight can be decreased when V string is used in heavy ice area, meanwhile the using of V string restricts the wind shifting of the insulator string, reduces the corridor width. Therefore V string is recommended to be used as conductor insulator string in heavy ice area. The maximum shifting angle of windward leg insulator string should be controlled within 7°, V string angle should be designed according to the following:

Table 2-8 Heavy Ice Area V String Angle (20 mm and 30 mm ice, 30m/s wind)

Tower Type	Kv Coefficient	Wind Shifting Angle (°)	V String Angle (°)
ZV21	0.85	40	70
ZV22	0.65	49.7	80
ZV23	0.75	44	75
ZV31	0.85	40	70
ZV32	0.65	49.7	80
ZV33	0.75	44	75

According to the conductor selection and separation number in heavy ice area, and based on mechanical load calculation, the conductor suspension V string configuration in heavy ice area of this engineering is as following:

The combination of each leg single joint 400kN and 550kN insulator strings and double joints 210kN, 300kN and 400kN insulator strings can be used for 20 mm ice area conductor suspension V string.

The combination of each leg double joints 210kN, 300kN and 400kN insulator strings can be used for 30mm ice area conductor suspension V string.

In order to avoid the uneven ice covering and the uneven force of double joints insulators or the collision of them when in off ice jumping, it is recommended to use single hanging point for double joints V type string in heavy ice area. Refer to Figure 7-5 for double joint V type strings arrangement in heavy ice area.

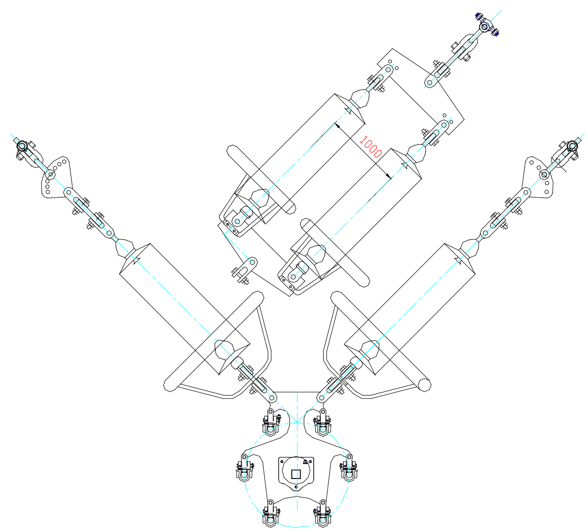


Figure 7-5 Schematic Diagram for Heavy Icy Area Double Joints V String

2.4.2 Conductor Tension String

1) The maximum load of each pole conductor tension string in 20 mm ice area is 436.3kN, therefore 3×400kN and 4×300kN types can be used as tension strings.

2） The maximum load of each pole conductor tension string in 30 mm ice area is 592.42kN, the insulator strength of the tension string is required to be 1599.5kN, therefore 3×550kN and 4×400kN types can be used as the tension strings.

Quadruple strings are with the shortcomings of complicated structure, more insulators and fittings, higher insulator failure rate during working, large maintenance workload, difficult to adjust when the two independently connected strings are with different lengths and easy to cause the long term uneven force of the insulator strings. While the triple joints structure is in a simpler structure, with even force, when the string lengths are different, it can get back to even force status automatically with the function of combination joints board, moreover, it is with the advantages of less insulators, lower failure rate and less maintenance workload. Therefore, triple string type is recommended for using.

That means 3×400kN tension string type is recommended to be using in 20 mm ice area and 3×550kN tension string type is recommended to be using in 30 mm ice area. Refer to the following for the recommended tension string arrangement:

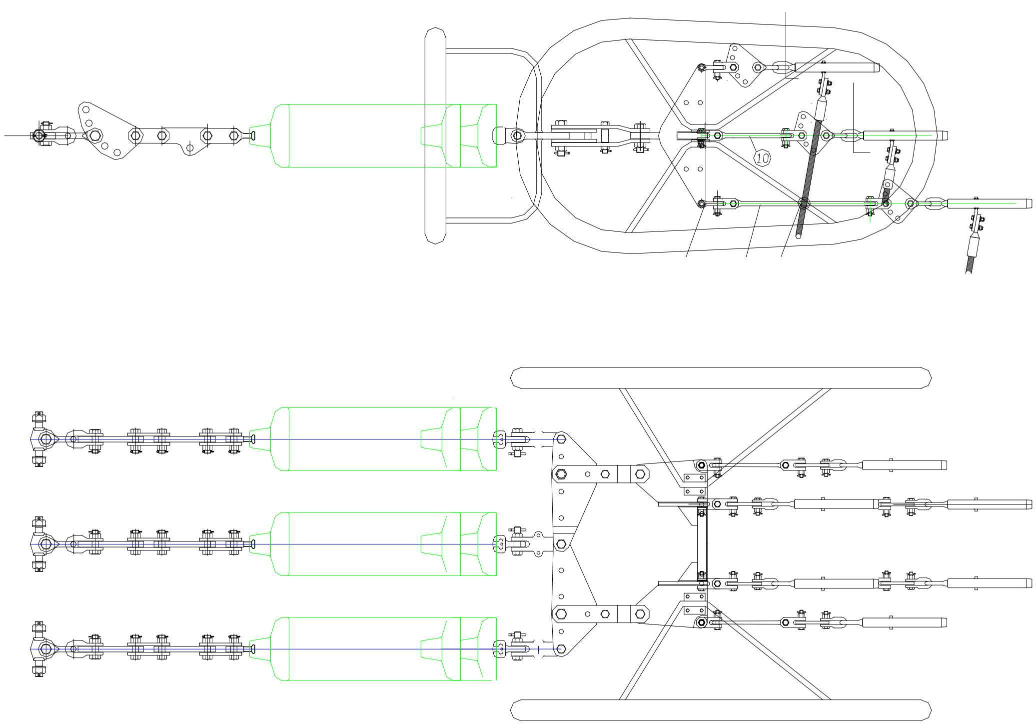


Figure 7-6 Schematic Diagram for 30mm Ice Area Tension String Arrangement

2.4.3 Joints Spacing

Off ice jumping is supposed to be happening to the insulator string in heavy ice area, which shall become more serious following the increasing of the thickness of the covering ice. After the conductor off ice jumping, the insulator string will be shaking severely, as there is too long a string length, the shaking of the string is more severe than that of 500kV line, if the joints spacing is too small, collision of the strings between the joints will be happening, at present there is no such kind of research in China and foreign countries, for safety purpose, appropriate joints spacing should be added in heavy ice area than in light ice area.

Table 2-9 Recommended Values for Conductor Insulator Strings Joints Spacing

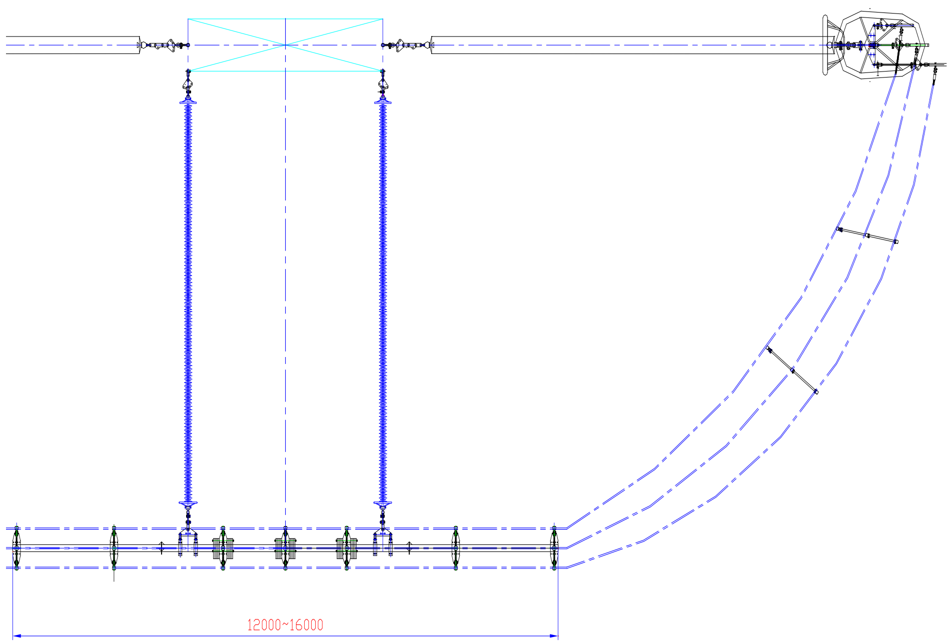
Ice Area	Suspension String	Tension String
Heavy Ice Area	800mm	1000mm

2.5 Jumper wire pattern

Reducing sag of jumper wire and angle of wind deflection is an effective method to reduce the dimension of strain tower. Sag of jumper wire and angle of wind deflection are related to patterns of jumper wire and rigid jumper wire. At present, strain tower has many patterns such as flexible jumpers, cage rigid jumpers and aluminum-tube rigid jumpers etc.

Flexible jumpers are widely applied in domestic circuits under 500kV. It possesses mature operation experience, but has great influence on cross arm dimension of strain tower. Compared to flexible jumper, cage type rigid is added with a support tube on basis of flexible jumper by a spacer damper. Besides, the jumper is fixed on support tube by spacer and support tube is connected to strain insulator string or strain tower through straining rod or stain insulator string. Though the sag of the jumper is small and cross arm of the strain tower is short, the installation is complicated. Compared to cage type rigid jumper, support tube of cage type rigid jumper and flexible jumper are replaced with two aluminum alloy tube,The aluminum aloy tube plays the role of conduction currecny and supporting and its installation is relative easy. But this method increases electric breaking point and corona can occur easily, especially in coupling area of aluminum tube and terminal, and with higher cost of manufacturing than cage type jumper. Therefore, cage type rigid jumper is recommended for strain tower.

At present there are two patterns of cage rigid jumpers of V-String and I-String. it will add an additional cost of RMB 6,580,000 by adopt V-String cage rigid jumper than I-string cage rigid jumper for the whole line. However, the property to avoid wind deflection of V-string cage rigid jumper and its electric reliability is better. Double V-string is adopted in cage type rigid jumper. It will help to fix rigid jumper and is the safest to electric reliability of the project. Therefore, it is recommended that double V-string cage rigid string be used. According to structure distribution and spacing analysis, the intersection angle of V-string should be 70～90°. Cage type rigid jumper should be arranged as follows:



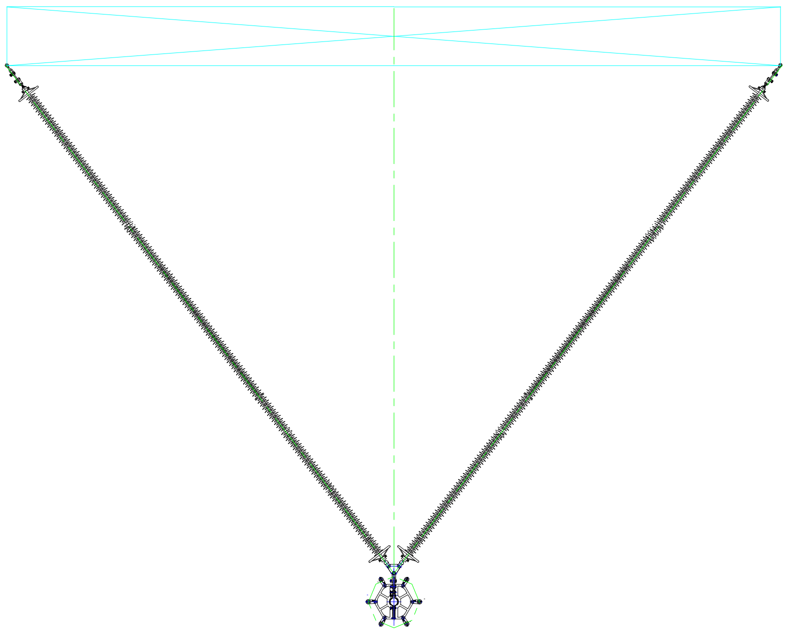


Figure 2-7 Diagram of arrangement of cage rigid jumper

2.6 Earth wire fittings

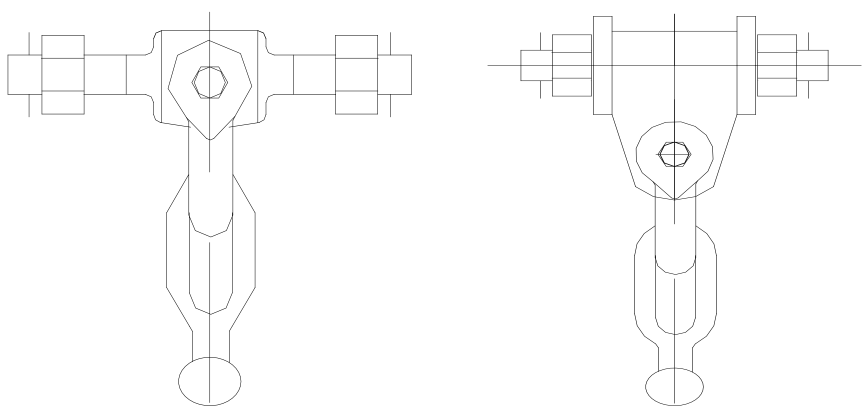
As being computed for mechanic property and tested for overload capacity on heavy icing area, 20mm of the earth wire and off-ice area shall adopt LBGJ-180-20AC aluminum clad steel standed conductor and 30mm ice area shall adopt GJ-210 galvanized steel stranded wire. Suspension fitting string of earth wire and strain fitting string should directly connected to the ground.

2.8 Main selection of fittings

Fittings mainly include tower-connecting fittings, suspension clamps, six-bundle yoke plates, spacer dampers, and grading rings. Fittings are the important parts connected to circuit for safe operation. If fittings become ineffective and damaged, circuit will be damaged and interruption of power supply will be caused. Therefore, fittings shall be of high reliability. They shall meet current related standards and other special requirements in this project. In addition, the conveniences to transport, install, repair, and replace fittings shall be taken seriously.

2.8.1 hardware fittings connected to towers

GD Clevises and GD trunnion clevises are the main two kind of fittings connected to towers in extra high voltage network. By use of these two fittings will avoid the irrational stress casued by UB Clevises and U-shaped assembly and improved the safety operation of transmission line. GD clevises reduce the space to the most of the run-on point of fair line and transverse line, in which improved the reliability of the hardware fittings connected to towers greatly. But they shall be installed when towers are being assembled. So the cross arm structure of towers becomes relatively complicated as the bolts are connected with the body leading to uneasy installation. The connection of GD clevises and trunnion clevises to other fittings is shown in the following figure.



(a) GD Connection method of GD clevis (b) Connection method of trunnion clevis

Figure 2-8 trunnion clevis and GD clevis

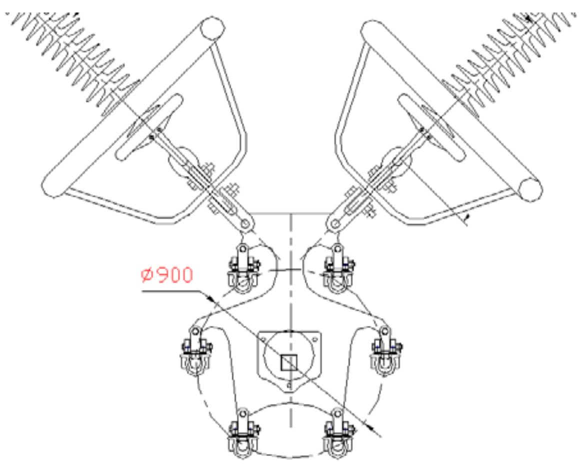
From the perspective of simplifying clevis design and construction convenience, trunnion clevises shall be adopted for suspension V-string hanging-point fitting. It is recommended that GD clevis or assembled clevises shall be used for strain hanging-point fitting and the diameter of threaded rod shall not be changed except the followings:

Adjust the diameter and thickness at connections of clevis and fittings.

According to design and operation experience of extra voltage transmission line and in consideration to factors like abrasion, the strength grade of fittings for connecting towers is generally higher than that of other connection fittings, i.e. matching the grade of insulator strength. According to the distribution condition of suspension string and patterns of strain string, there are six strength grades of fittings for connecting towers, are 320kN, 420kN, 530kN, 640kN, 840kN, and 1060kN. Whole forging workmanship shall be used to process fittings for connecting towers.

2.8.2 Six-bundle suspension yoke plate

The key hardware fittings in suspension string is the type selection of six-bundle suspension yoke plate, which adopts combination yoke plate and integral yoke plate in 750kV AC transmission line.The six-bundle suspension yoke plate of 500kV compact line in China all adopt integral type, which have the advantage of stability, fewer hardware fittings, simply structure, but heavier for single part. It is easy to transport in mountainous area from the experience of design and construction. Therefore, the integral six-bundle suspension yoke plate is recommended in this project. Six-bundle suspension integral yoke plate is as the following drawing:

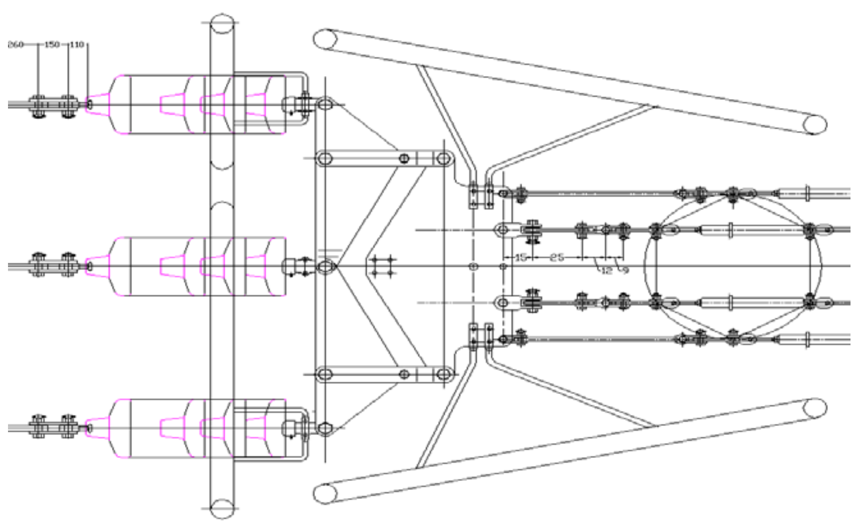


Drawing 7-9 Sketch map of six-bundle Suspension yoke plate.

It may adopt 420kN、640kN、840kN、1280kN、1680kN (In heavy icing areas) because the strength of suspension yoke plate is same as the strength of insulator string.

2.8.3 Six-bundle tension yoke plate

The six-bundle tension yoke plate also has two types: integral and combination type . The integral type is good in stability, fewer hardware fittings, simply structure. The single piece of combination yoke plate is easy to fabricated, transport and installation of its light weight. It recommends combination yoke plate to the project area with 20mm and below, due to integral yoke plate is weight 200kg for a single part, it is inconvenient for transport and installation. While for the area of 30mm icing areas, it is recommended to use integral type because of good stability of integral type. The following drawing is the recommended six-bundle tension string combination yoke plate and integral yoke plate when tension string adopts 3×400kN insulator string.



Drawing 7-10 Sketch map of six-bundle Tension yoke plate

The strength grade of six-bundle tension yoke plate which is matched with 3×400kN tension insulator string is 1280kN. The strength grade of six-bundle tension yoke plate which is matched with 3×550kN tension insulator string is 1590kN.

2.8.4 Suspension clamp

The corona issue of hardware fittings shall become a major problem by the increasing of voltage in HVDC line. There are two anti-corona methods for suspension clamp: one is to adopt Corona free suspension clamp; the other is to add shielding ring for anti-corona. It recommends Corona free clamp to use as the project suspension clamp because Corona free suspension clamp has been widely used in 500kV and 750kV HVDC line in China.

Carried-up type suspension clamp is mainly used in flat area. It may adopt Carried-up suspension clamp because the hills, flats and river network of the project is about 870km, then if it is adopted, it shall pay high attention to its corona features. Besides, it needs to research the voltage share of insulator string. From the present research result, it needs to raise Grading rings to the place of three pieces insulator, about 550mm. while it need further research about how much to go deep for insulator string if Carried-up suspension clamp is adopted, because it can not raise the enough height according to same height. So in the report, it is temporarily not recommend Carried-up suspension clamp in hills, flats and river network.

The main difference between trunnion type and Envelope type suspension clamp is the relative position between shaft and vertical axis of suspension clamp. IEC standard only requires that rotation axis shall have enough wear resistance but without specification. CIGRE standard recommend that rotation axis shall not be higher than the conductor diameter of 1 to 2 times conductor axis, which can make the inertia moment of rotation axis as small as possible to reduce dynamic stress. The design of suspension clamp shall ensure the vibration of conductor and clamp to a minimum to avoid any damage towards conductor caused by stress.

When conductor swing up and down in vertical direction, the torque of it towards swinging up and down of suspension clamp is small, because of the stressed shaft of trunnion type suspension clamp is on the axle wire of conductor, that's to say the caused stress by the swinging up and down of suspension clamp is small to conductor, and will minimize the fatigue damage of conductor to the most, especially the conductor fatigue damage at line outlet area.

The AGS suspension clamp have the advantage of protect the conductor well and minimize the damage to conductor. It is mainly used in OPGW, and may used to protect conductor abroad. Due to the well protective property of AGS suspension clamp, we adopt AGS suspension clamp to the first 750kV transmission line in China, which the mostly applied to the large diameter conductor. We do not recommend the AGS suspension clamp because the cross section of current widely used conductor is small and no running experiences of applied to the conductor with large cross section.

To ±800kV HVDC transmission line project, it not only need to adopt products with high performance, but also to use these products with abundant experience under operation, so it suggest to adopt the common Envelope type suspension clamp suspension clamp to the HVDC transmission line in China.

Other requirements for suspension clamps are,

1) The overhanging angle of suspension clamps should no less than 25°;

2) The curvature radius of the hull's slots should not less than 8 to 10 times of the diameter of the conductors; and the contacting area between the wire clips and the conductors should remain smooth;

3) The suspension clamps on the line should be able to turn flexibly; and the swinging angle should no less than ±30°;

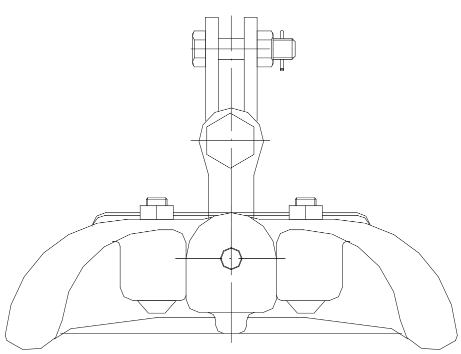
4) There should be enough contacting surface between the suspension clamps and the installed conductors, and the damages caused by fault current will minimize.

5) The grip strength of the suspension clamps should no less than 24% of the calculated tensile strength of the conductors;

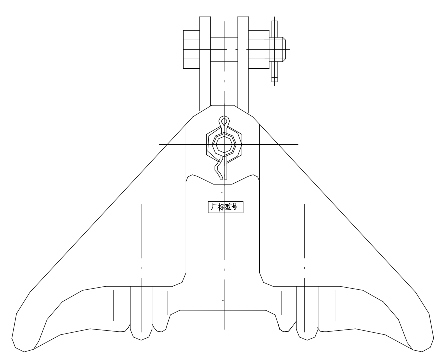
According to the situations of the suspension string applied to this project, the strength of suspension clamps will classified to four grades, 100kN, 160kN, 210kN and 300kN (for the heavy ice zones).

it is usually install the preformed armor rods at the condition of large vertical span, therefore, the suspension clamps need meet the requirements for installation.

The suspension clamps commonly divided into envelope type and trunnion type, which used for extra-high voltage transmission line. The trunnion type suspension clamps are poplar in oversea countries, while the envelope type suspension clamps are used in China, basically ,for all the extra-high voltage transmission lines. Please see the following diagrams for the envelope type and trunnion type suspension clamps.



The trunnion type suspension clamp



The envelop type suspension clamp

Fig. 7-11 The suspension clamp types

For ±800kV EHV DC transmission line projects, it is required to used products with good performance; and also have the requirement on the products of large operation experiences. So, the envelope type suspension clamps, which have abundant operating experience, are recommended for this project.

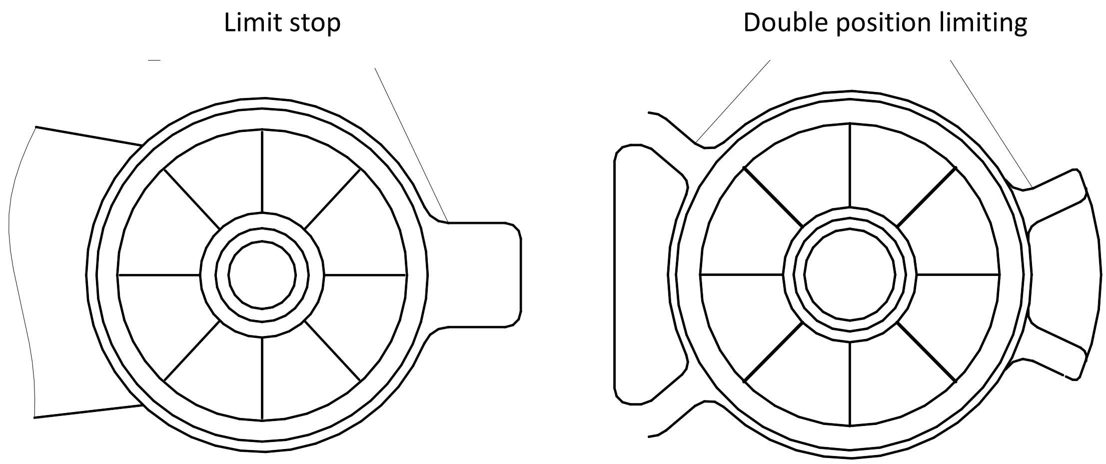
2.8.5 Spacers

There are two types of spacers, one is the integral type, the other is spread-assembled type. integral type spacers were adopted for ultra-high voltage line project in the Former Soviet Union, and spread-assembled type were once used for extra-high voltage transmission lines and in the testing stages of 1,150 kV.

In Japan market, it is adopted integral type spacer with spring, and without elastomer. The energy will consume by the contraction of spring and will led clamps able to turn flexibly, to achieve the purpose of eliminate the vibration. It is adopt the Integral type in China, applied to the 500kV and 750 kV transmission lines, therefore, integral type spacers are recommended.

Due to the convenient installation and reliable grip strength of hinge type clamp assembled with pins , it is widely used up to now. And this type is also used of this design, the two differences are, that it is add a structure on the pins to limit the position, and have the advantage of fixed pin position while installation; the pins will hardly fall when the structure limiting the fastening pins after the conductors are gripped by the clamps.

In order to allow the clamps to rotate around the joints to ±15°, the problem of position limiting between the clamp body and the spacer frames, which was solved by designing a convex part (or called the limit stop) at the tale of the joint in the past, should be taken into consideration. For more reliable position limiting, it is recommended to adopt double position limiting design, which will limit the position at the reverse direction besides the tale part of the limit stop.



(a) The traditionally designed Position limiting of clamp rotation

(b) The design of double position limiting

High-strength bolts shall used for connecting tthe clamps and the body frames, that will to led convenient to replacing the clamps if needed. It is required that the spacer bodies installed at the lines should completely surrounded by the bundle sub-conductors. And the tension (pressure) strength between clamps is generally required no less than 6.0 kN. Too short clamps will increase the weight of spacers and will easily cause corona; while over-long clamps will lead to over-large bending torque and is not easy to ensure the strength. Referring to data from domestic and abroad, it is relatively suitable to set the distance of 150 mm between the center lines of the conductors to the joint axis.

The spacers are classified into rigid and flexible spacers. The rigid spacers will prevent any shifting between the sub-conductors, however, the effectiveness to prevent aeolian vibration and restrain sub-span oscillation is not good, therefore, flexible spacers are mostly used in the world. Due to the different damping types of the flexible spacers, generally could classified into two types, one is elastomer damping type and the other is spring damping type.

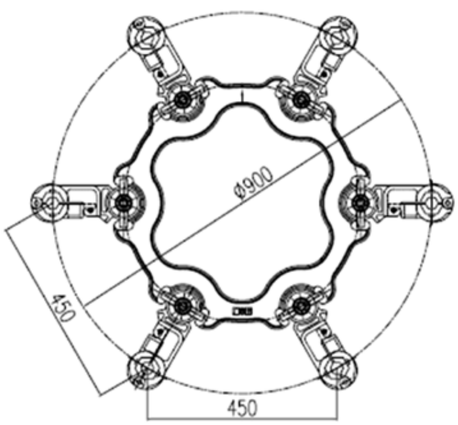
Strictly speaking, the spring damping type spacers cannot consume energy of vibration, only storage the energy by using the springs and then release it slowly. While by embed the elastomer in the joints, the elastomer damping type spacers will consume the energy of vibration, which obviously restrain the aeolian vibration and sub-span oscillation. And as our experience, the effectiveness are perfect. To install the elastomer damping type spacers with unequal space is recommended.

The clamp head of spacers may fall off and led to damaged under the huge forces of the rotation and dancing phenomena caused by covering ice in heavy ice zones, especially the jumping of conductors because of ice.

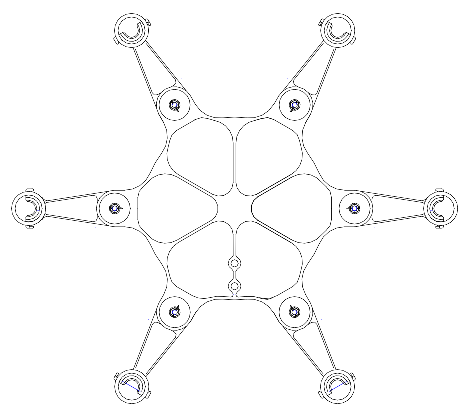
That will effect the safe operating of the transmission lines. And there is already successful operating experience adopt preformed spacers to slove the problem

.

As above listing, elastomer damping type integral spacers are recommended in light ice zones, while preformed type spacers are recommended in heavy ice zones.



(a) Spacers for light ice zones



(b) Spacers for heavy ice zones

Fig. 7-12 The recommended types of spacers

2.8.6 Equalizing ring, shielding ring

For ultra high voltage ±800kV DC transmission line, because of the voltage level increase, the number of insulators will be increase greatly than that of extra high voltage line. In insulator string, the voltage borne by single piece of insulator will also increase.

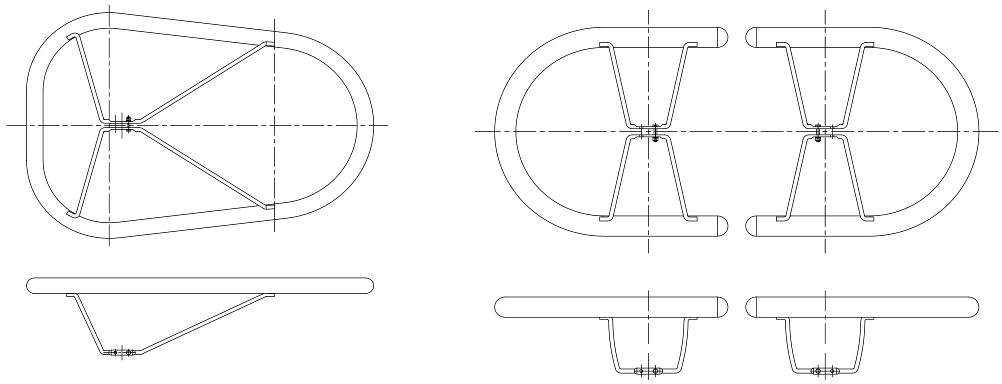
For the safe working condition of the insulators, the voltage borne by single piece of insulator of ultra high voltage line shall not increased greatly compared with that of extra high voltage, that's to say the required that voltage percentage borne by single piece of insulator of extra high voltage shall decrease, which requires a relatively great improvement in the design of corona ring.

For the tension insulator-strings, due to the coupling length is relatively long, with more the quantity of joining fittings, and the coupling type is complex, in order to elinimate the corona loss of the fittings, as well as the radio inference and audible noise level, it's necessary to proceed effective shield to the fittings of tension string.

Guidance to the design and assembly of corona ring and shielding ring are as follows list:

For suspension string and tension string, the installing position of grading ring is between the second and third piece of insulator, the equalizing effect is relatively good, diameters of both grading ring and shielding path adopt aluminum tube of 120mm, which the radius of grading ring is 620mm.

Suspension string could only installed grading ring, no more installation of shielding ring, and tension insulator string could installed with shielding ring and grading ring. Both shielding ring and grading ring of tension string are shown as the following figures.



Grading ring of tension string Shielding ring of tension string

Figure 7-13 Grading ring and shielding ring of tension string

2.9 Suggestions

(1) Suspension insulator in light pollution area may adopt disc-type insulator or composite insulator, which shall chosen for configuring with the factors of climate conditions, operation experience and the type of insulator string. The insulator of suspension string in medium and heavy pollution area are adopt composite insulators. Tension insulator adopts disk-type insulator.

(2) It is recommended that adopt type V insulators as the main suspension string in the light ice area of this project, the angle of type V string in light ice area adopts 90~100°. For tangent angle tower, it is recommended to adopt type L insulator string.

(3) Due to this project adopt duplex connection, and hinged joints between two side of yoke plate are relatively more, that will not consider change the ball and socket couplings aside the line connectoed the composite insulator; while full-part insulator can be temporarily considered for the use of preliminary design, two-parts composite insulator will be taken as the comparison proposal after the conduct the electric true type test and after verification in the future.

(4) Tension string in light ice area of this project is recommended three-connection horizontal arrangement for 400kN disc-type insulator.

(5) It is suggested that scientific research unit conduct the test of distance between the connections, to validate the relations of flashover voltage between the duplex connection structure and single connection structure.

(6) It is suggested to adopt rigid jumper with double V string of this project. The angle selection of V-type string is 70~90° based on structure arrangement and clearance analysis.

(7) Selections of the primary fittings

(1) For hanging point hardware & fittings of V type suspension string, Trunnion Clevis is adopted. It is suggested to adopt GD clevis or assembled clevis as the hanging point hardware fittings of the tension insulator-string, and the diameter of screw will not change, only to adjust the hole diameter and thickness at coupling area between the clevis and hardware fittings. Hardware & Fittings of tower-connected shall be fabricated as integral forging.

(2) Integral yoke plate is recommended for six bundles suspension yoke plates of this project, combined yoke plate is recommended for strain yoke plate of this project in 20mm and lower-than-20mm area. When in 30mm ice area, because of ice covering is severely, the stability of integral forging is relatively good, so is recommended.

(3) Corona free envelope-type suspension clamp is recommended for the use of this project.

(4) It is recommended to adopt elastomer damping spacer for the light ice area, and preformed type spacer for the heavy ice area of this project.

(5) For suspension string and tension string, the installing position of grading ring shall between the second and the third insulator, the voltage sharing result is relatively good. Both the diameter of grading and shielding ring all adopt tube of 120mm, the radius of grading ring is 620mm. Suspension string is only installed the grading ring, and no more installation of shielding ring.