Advances in UHV Transmission and Distribution
Prof. B Subba Reddy
Department of High Voltage Engg (Electrical Engineering)
Indian Institute of Science, Bangalore

Lecture – 18
Mechanical considerations for HV conductors

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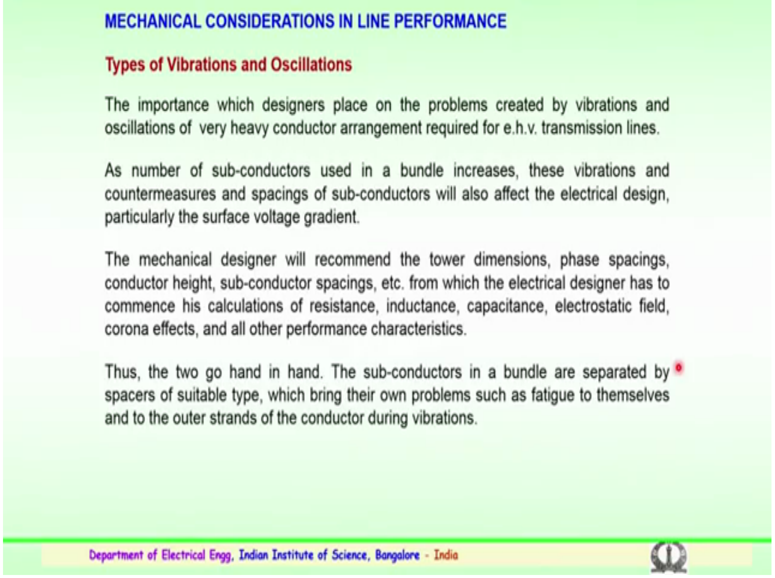

So, we have seen various types of conductors which are being used for the transmission and distribution for the high voltage and ultra high voltage levels. We will look into the mechanical consideration about the line performance that is particularly during the vibrations, which conductor undergoes. The various types of vibrations and the oscillations which are created are very important while designing the conductors or the estimating the e h v, or UHV transmission lines, these oscillations have to be taken into consideration.

The problems particularly related to vibrations and oscillations of very heavy conductor arrangement. The four bundle or a quadruple bundle or a six bundle or eight bundle conductors, which are at extra high voltage or ultra high voltage transmission systems have to be considered. As number of sub-conductors in the bundle increases, the sub-conductor bundle could be 2, 4, 6, 8 or more, these vibrations and a counter measures and spacing of sub-conductors also will affect the electrical design particularly the surface voltage gradients which we have seen. So, the mechanical designer had to recommend the tower dimensions for a particular voltage level, the phase spacing, the conductor height, the sub-conductor spacing etcetera from which the electrical designer has to commence his calculations of the resistance, the inductance, the capacitance, the electrostatic field, the effects due to corona, visible discharges and several other performance characteristics.

So, the both the mechanical and electrical designers have to go hand in hand. As the sub-conductor in a bundle are separated by the spacers of suitable type if it is a twin, twin spacer, if it is a quadruple that is the four bundle conductor it will be a quadruple type of a spacer. This bring their own problems such as fatigue to themselves, and to the outer stance of the conductor particularly during the vibrations which the conductor bundle experiences. So, important considerations for the design aspect.

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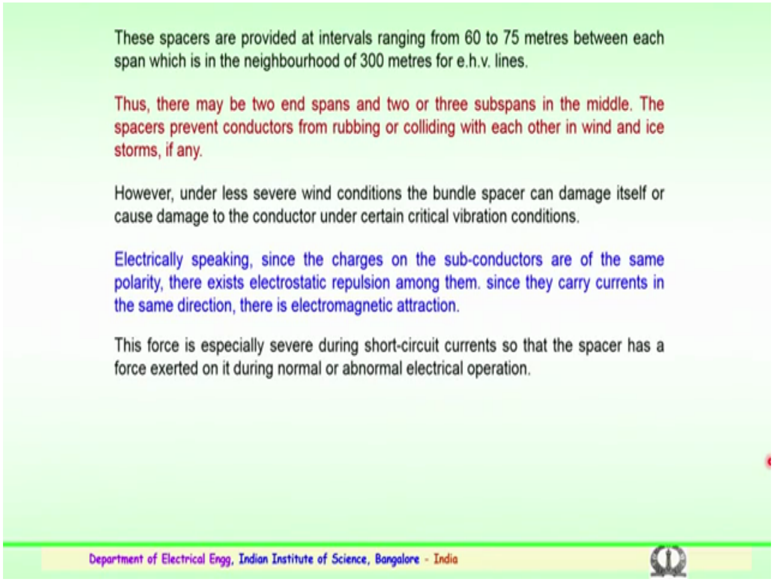

So, these spacers either twin, triangular type that is a three conductor bundle spacer or a quadruple or a more are provided at an intervals ranging from anywhere between this 60 to 70 meters from the tower side between each span, which is in the neighborhood of typically around 300 meters for extra high voltage lines. So, thus there may be two end spans and two or three subspans in the middle depending upon the span length. The spacers prevent the conductors from coming together that is rubbing or colliding with each other in the wind and in ice storms, if any of the transmission conductors which are operating in high altitude and areas where ice formation is happening continuously. So, that is one of the reason where the conductor distance has been a maintained.

However, under less severe wind conditions these bundle spacer could be damaged by itself or cause damage to the conductor under certain critical vibration condition. So, very important point to be considered for using the type of spacers where it could damage itself or it could damage the conductors depending upon a particular vibrations which it sees in the field. So, electrically speaking, since the charges on the sub-conductors that is depending upon number of sub-conductors are of the same polarity, there exist electrostatic repulsion among them, since they carry currents in the same direction. So, there is a electromagnetic attraction between these sub-conductors. So, this force is especially severe during short circuit currents so that the spacer which is provided has a force which is exerted on it during normal or abnormal electrical operations. So, the spacer will be seeing the force during normal or abnormal operations.

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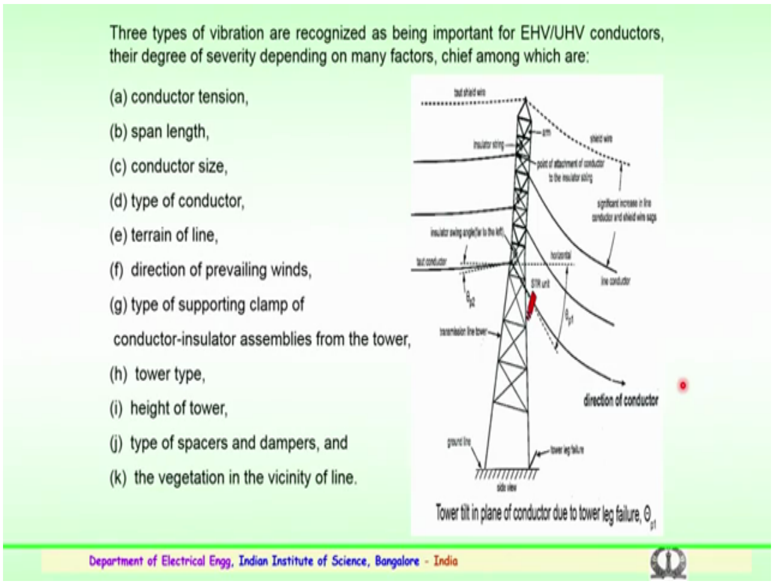

The three types of a vibrations are recognized as being very important for the extra high voltage or ultra high voltage conductors which are used for the transmission. Their degree of severity depends on many factors. The primarily some of the factors are the conductor, tension, the conductor which is being held at a particular tension, the span length depends from conductor to conductor, the conductor size which is being used for the transmission. What type of conductor which is being employed, then the tower and the terrain of the line, whether it is a flat or a altitude or a mountainous area or a forest, so the terrain of the line. The direction of the prevailing winds, how the wind blows in that particular area. The type of supporting accessories or a clamps which are used for the conductor and insulator assemblies from the tower side, then the type of a tower which is in operation or which is being used for the transmission; the height of the tower. The type of spaces and the dampers which are used for the conductors the vegetation or the as mentioned the forest near the vicinity of the transmission line.

So, several of these factors play a role in a type of vibration which is happening on the conductors, there will be a forces in different directions, it could be horizontal or it could be different types. A simple a tower a tilt in plane of conductor due to lower leg failure could be seen here in case of the foundation, there is a weak junction then the entire force significant increase in the conductor. And the shield wire sagging of the line conductor then the horizontal movement and the direction of the conductor could be spring and insulator string different directions. So, several of this parameters are factors could influence the tower during the operation.

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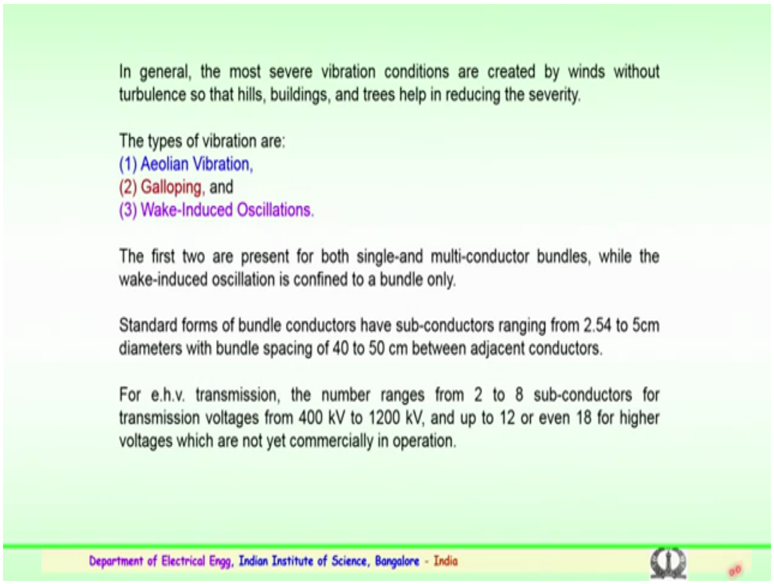

So, in general most severe vibrational conditions are created by winds without turbulence so that hills - a mountainous areas, buildings and trees particularly help in reducing the severity. So, any turbulent winds could be blocked by these high rise buildings, hills, trees an extent, but the type of vibration some other types of vibration or known as the

Aeolian vibration, the second is the galloping and the third is a wake-induced oscillations. So, these three types of vibrations are to be noted for the transmission engineers, and have to be considered while designing the transmission lines.

So, the first two that is a Aeolian and the galloping type of vibrations are normally present for two types that is a both the single and multi conductor bundles. It could be for a very low voltage or it could be a higher voltages. While the third or a wake-induced oscillation is confined to that particular bundle conductor only bundle conductor again it could be twin, or it could be four – quadruple, or it could be eight conductor. So, this wake induced oscillations are confined to that particular bundle.

The standard forms of a bundled conductors which are having sub-conductors ranging from 2.54 to 5 centimeter diameter with bundle spacing as mentioned; in India we use 45 centimeter between adjacent conductors so that is a standard which is being followed. For extra high voltage or ultra high voltage transmission, the number ranges anywhere between 2 to 8 sub-conductors for transmission voltages from 400 kilovolts to 1200 kilovolts, and sometimes more than 12 or even 18 for voltages which are not yet a commercial in operation. Where experimental experimentation is in progress particularly for 1200 kV, 12-bundle conductor is being employed for the experimental purpose. So, these are the facts about the various sub-conductors in a bundle used for e h v or UHV transmission system.

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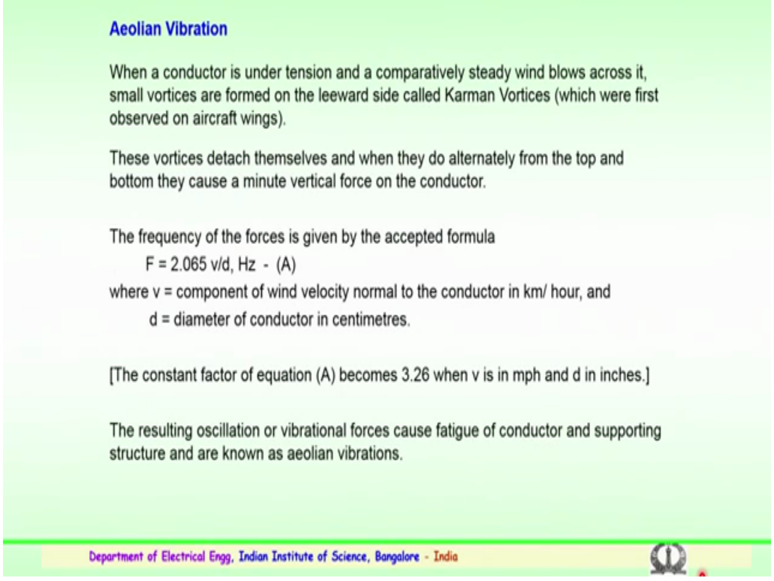

So, we will be looking into the three types of vibrations which are seen in the transmission and the effects due to these three types of vibrations. And how do we counter these phenomena in the transmission that is the important for the transmission engineer. And what are the advanced accessories or the type of gadgets which are being used to contain this forces various type of vibrations. So, the Aeolian vibration happens when a conductor particularly is under tension and comparative a steady wind blows across it, a small vortices are formed on the leeward side called Karman vortices which were first observed on the aircraft wings, this seen on the aircraft wings initially.

So, a Karman vortices type of arrangements were seen, these vortices detach themselves when they do alternatively from top and bottom, and they can cause a minute vertical force on the conductor. So, small swinging of the conductor in the vertical force on the conductor will create on the conductor. This frequency of the forces, which happens on the conductor is given by the formulae f is equal to 2.065 v by d hertz, where v is a component of wind velocity which is normal to the conductor and it is given in kilometer per hour; and d being the diameter of the conductor in centimeters.

So, the constant factor of equation A, which is given here becomes 3.26 that is instead of 2.065, it becomes 3.26 when the wind velocity is considered in miles per hour that is in case of kilometer per hour, we have to use 2.065. And when it is miles per hour we have to use 3.26 as the constant factor. And d earlier, it is in centimeters, when you are using 3.26 you have to use it in inches. So, this is the modification when the formula is being used for miles and inches. So, the resulting oscillation or the vibration forces could cause fatigue on the conductor and supporting structure also. And this type of oscillations or vibrations are known as Aeolian vibrations, which normally form the vortices and detach themselves when the alternately from top and to the bottom.

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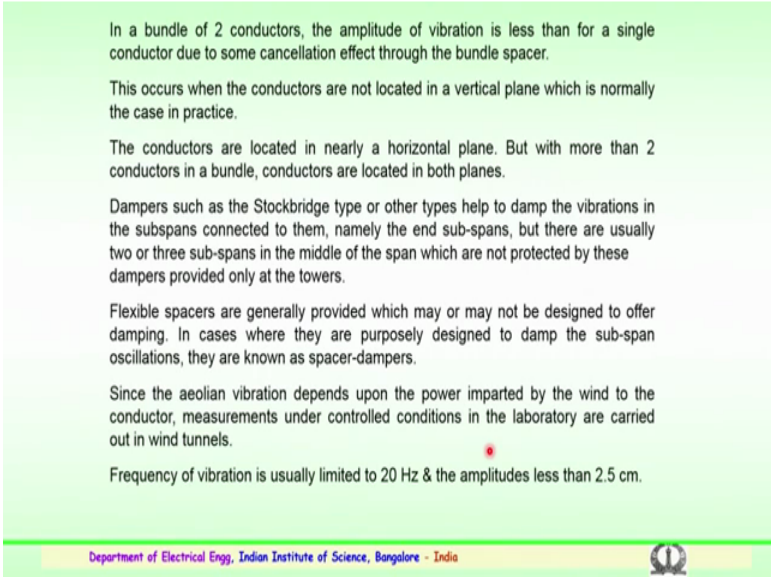

So, considering a two bundle of two conductors, the amplitude of vibration is less than for a single conductor due to some cancellation effect through the bundle spacer. So, you have spacer between the two conductors. So, the amplitude could be less for a particular single conductor because of the effect of bundle spacer. And this occurs when conductors are not located in a vertical plane which is normally the case in practice. So, the conductors are located nearly horizontal plane when more than two conductors in a bundle the conductors will be seen in both the horizontal and as well as the vertical planes. So, for this countering action, dampers such as the Stockbridge type or other type of dampers help to damp the vibrations that is the Aeolian vibrations in the sub spans connected to them and at the end of the sub spans. But there are usually two or three sub spans in the middle of the span which are not protected by dampers provided only at the tower ends. So, that is a reason where flexible spacers are generally provided which may or may not be designed to offer damping in cases where they are purposely design to damp the sub span oscillations, which they are known as spacer dampers.

So, since the Aeolian vibrations depends on the power imparted by the wind to the conductor, measurements under controlled conditions in the lab are carried out in wind tunnels. And the frequency of vibration is usually limited to 20 hertz, and the amplitude is less than 2.5 centimeter. So, this is very important 20 hertz frequency and vibration dampers are being used to cut in the oscillations. So, we will be looking into the types of dampers and the spacers which are being used in the future discussions.

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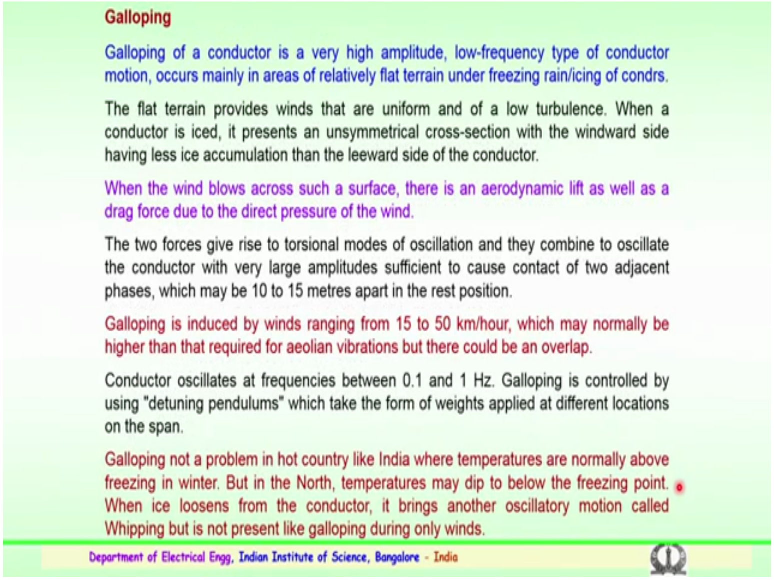

The second type of vibration or the effect is known as galloping. The galloping of the conductor is very high amplitude, and this is a low frequency type of a conductor motion and occurs mainly in areas of relatively flat terrain. So, the towers which are on the flat terrain undergo this type of conductor vibrations known as galloping, and also are observed under freezing rain and icing on the conductor. So, this phenomena is seen in the cold countries. The flat terrain provides winds which are uniform and of a low turbulence, so not much of a velocity. When a conductor is ice the conductor is loaded with ice it presents an unsymmetrical cross section with the windward side having less ice accumulation than the ice ward side of the conductor.

So, the wind blows in case across such a surface there is a aerodynamic lift or the conductor sees a lift as well as drag force. This is due to the direct pressure of the wind on the conductor, which is loaded with the ice. The two forces because of the pressure gives rise to torsional modes of oscillations, and they combined to oscillate the conductor with large amplitude and this will be sufficient to cause contact of two adjacent phases that is different phases in the tower which may be 10 to 15 meters apart in the rest position. So, this could come in contact. So, the galloping is induced by winds ranging from 15 to 50 kilometer per hour to point to be noted here which may normally be higher than the required for Aeolian vibrations which are of lesser speed, but there could be an overlap.

So, the conductor oscillates at frequencies at a very low frequency 0.1 and 1 hertz. So, there it was 20 hertz, here the conductor could oscillate at less than 1 hertz. So, galloping is controlled by using detuning pendulum. So, earlier we used the vibration damper here detuning pendulums which take the form of weights applied at different location on the span. So, the weights are intentionally added to detune the oscillations because of the galloping. Particularly, galloping is not a serious problem in the hot countries like India where temperatures are normally above freezing inventor, but except few places where this problem could be seen in the Northern Himalayas and the areas where freezing during winter. But in north temperature may dip below the freezing point when ice loosens from the conductor, it brings another oscillatory motion called whipping, but it is not present like galloping during only winds. So, this is a second important vibration which has to be curtained to see the conductor oscillation is avoided.

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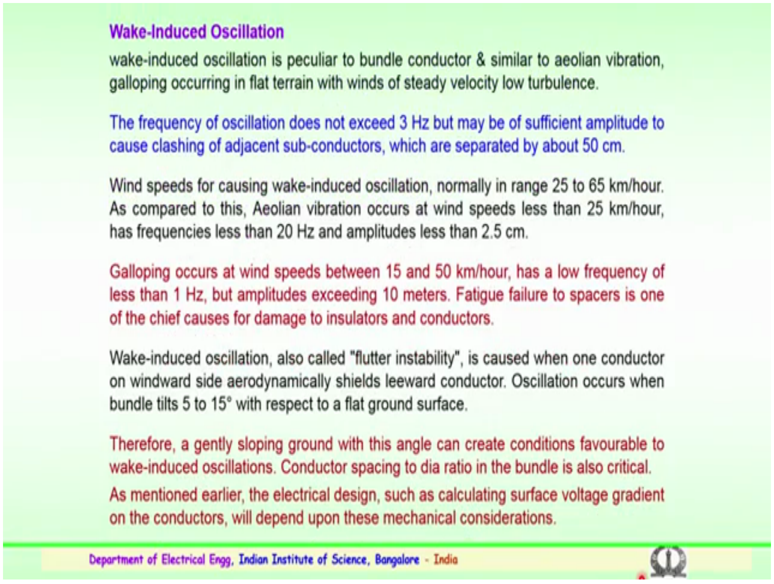

The third is the wake-induced oscillation or a vibration this peculiar to the bundle conductor that particular bundle consisting of twin two conductors or four conductors or eight or many more. And this is similar to the Aeolian vibration. Here the galloping occurs in a flat terrain with winds of steady velocity particularly blowing through a low turbulence. So, the frequency of oscillations in the wake-induced oscillations does not exceed 3 hertz, but may be sufficient amplitude to cause clashing of adjacent sub-conductors which are separated by about 45 centimeters in case of India, and 50 centimeter elsewhere.

So, wind speeds for causing wake-induced oscillations normally range in 25 to 65 kilometers per hour as compared to this. The Aeolian vibration at wind speed occurs less than 25 kilometer per hour as frequency less than 20 hertz and amplitude less than 2.5 centimeter. So, similarly galloping occurs at wind speeds between 15 to 50 kilometers you can see the difference here has a low frequency of oscillations less than 1 hertz. So, here it is 3 hertz, here for galloping it is 1 hertz, but amplitude exceeds 10 meters. So, here is a point where the fatigue or the failure due to spacers is one of the main causes to damage the insulators and the conductors. So, that is a point to be considered the galloping causes the spacer to be become fatigue and also the space failures for the insulator and conductors.

The wake-induced oscillations also causes a flutter instability. This is caused when one conductor or windward side aerodynamically shields leeward conductor. So, the oscillation occurs when bundle tilts to 5 to 15 degrees with respect to flat ground surface that is a point. So, the wake-induced oscillations, in case there is a tilt or a shift in the conductor bundle because of the oscillations aerodynamically, this could cause wake-induced type of oscillations. Therefore, a gently sloping ground with this angle could create conditions favorable to wake induces oscillations the conductor spacing to diameter ratio in the bundle is also very critical. That is how a proper choosing of the bundle conductor with the dimension of the conductor is a very important aspect which has been mentioned earlier the electrical design such as a calculating surface voltage gradient on the conductors will depend upon these mechanical performance of the conductors in the transmission system.

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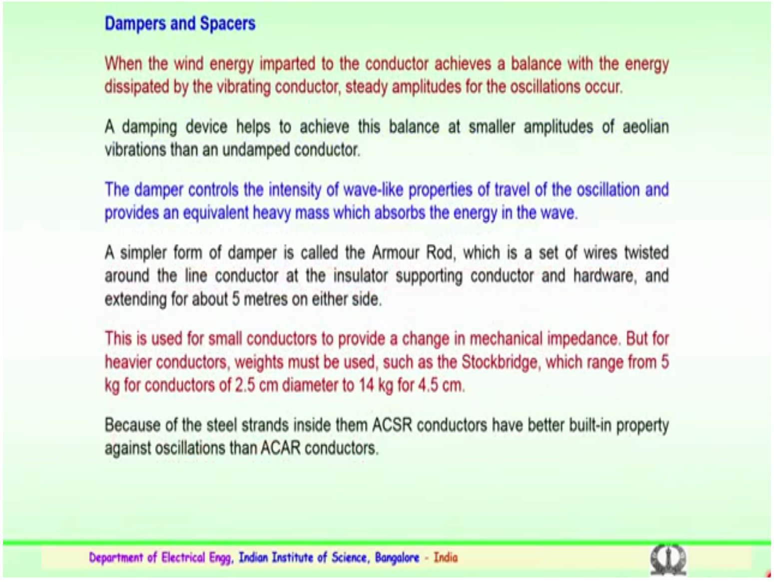

So, for this three types of vibrations or oscillations which we have discussed important components are the dampers and spacers, these are used to see the vibrations and the oscillations which the conductor experiences have to be reduced. So, the wind energy imparted to the conductor achieves a balance with the energy dissipated by the vibration conductor or steady amplitudes for the oscillations do occur. So, a damping device a damper or damping device helps to achieve these balance at smaller amplitudes of Aeolian vibrations than an undamped conductor. So, the damper controls the intensity of a wave like properties of travel of the oscillation and provide an equivalent heavy mass which absorbs the energy in the wave. So, oscillations containing the higher energy will be absorbed by the damper and tries to reduce the oscillations a simple form of damper is called the Armour rod. So, when the conductor is connected to the insulator string with the Armour rods this is around the simplest damper where the oscillations are reduced which is a set of wires twisted around the line conductor at the insulator support and hardware.

So, the extending for about 5 meters on either side, total around 10 meters, this is used for small conductors to provide a change of mechanical impedance. But for heavier conductors with large number of spans the weights must be used such as the Stockbridge type of a spacer, which range from 5 kg for conductors 2.5 centimeter to 14 kg for a 4.5 centimeter. So, because of the steel strands inside the ACSR conductor have better built in properties again oscillations than the ACAR conductor.

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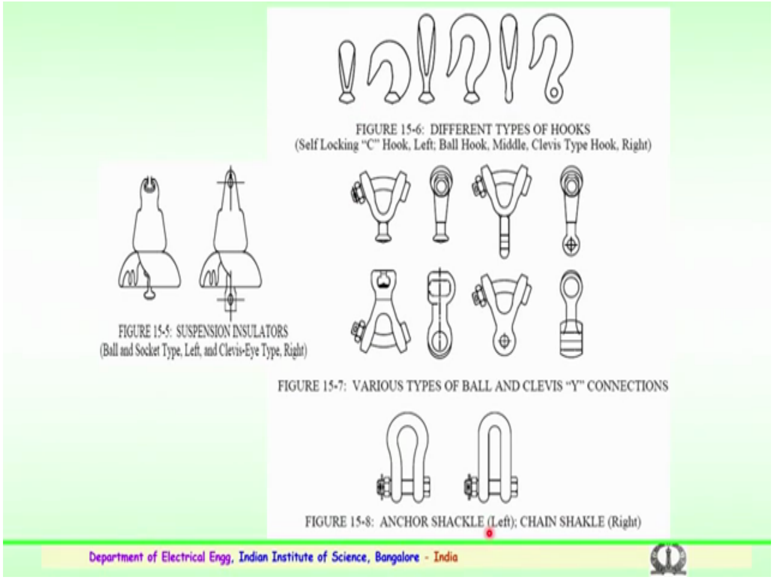

So, these are various types of the connectors a hook which are being used for the transmission system, various type of a hooks for the insulator conductor and the accessories which are being employed for the transmission and also for the distribution systems various types or different voltage levels.

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These are again the clamps for connecting the conductors very important for joining the conductor and terminations at the tower ends.

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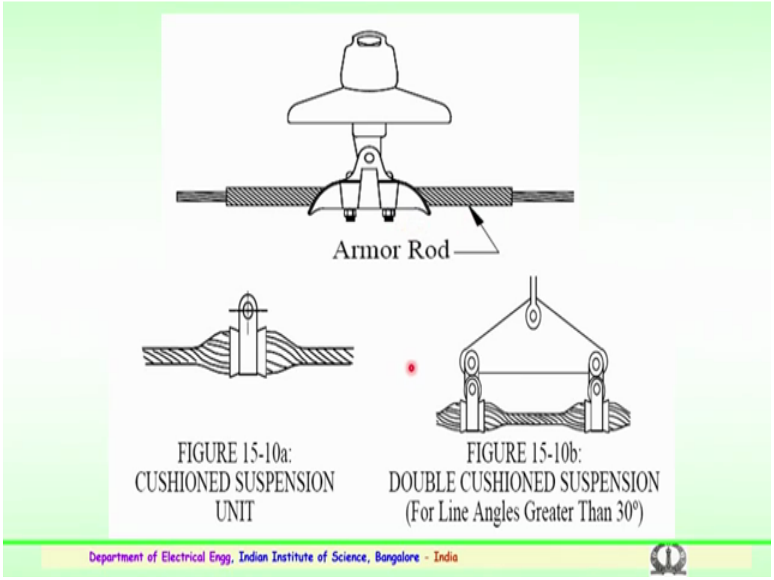

This is the armor rods which initially will suppress the oscillations you can see from the insulator string after the necessary clamps. The twisted conductor is armor type of conductors which either side of 5 meters on the conductor are twisted to see that the vibrations caused by Aeolian or galloping or wake-induced oscillations are reduced in case of a single conductor bundle.

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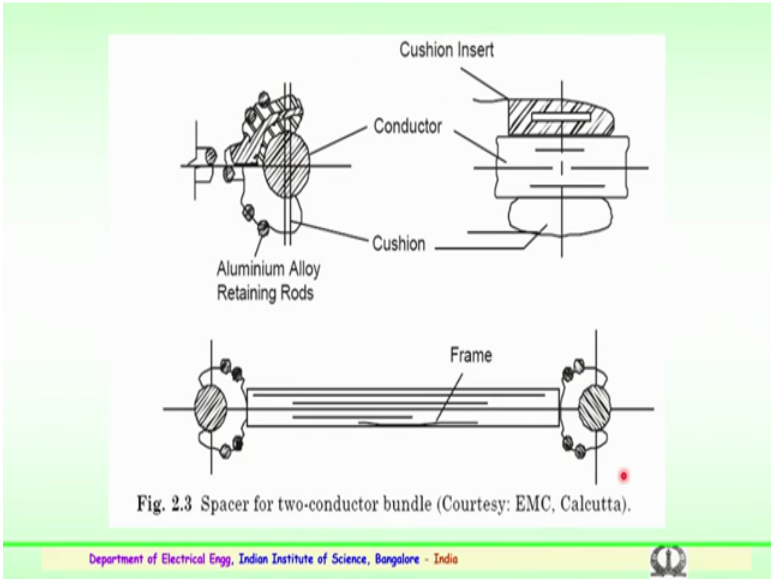

So, this is one of the type of spacer. The spacer for two-conductor bundle you have one conductor other conductor the distance between the spacer that is the aluminum metal frame is 450 mm that is 45 centimeter in case in the country in India we adopt 45 centimeter distance between each conductor. So, this has again cushion which is inserted with the conductors properly spaced on the spacing or two ends of the spacer, this is a twin spacer for two conductor bundle.

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Similarly, we have several accessories very important, a conductor accessories which are used for transmission and distribution. You have a terminating or end clamps, dead end clamps. You have mid span compression joint where this helps to join the two conductors to continue the transmission lines. This is again a spacer to keep 450 mm distance. And this is a T connector; this is a repair a sleeve in case the conductor gives away some strands, so has to be properly repaired. So, this repair sleeve will bind the conductor at the junction where the conductor has become week or needs to have repair.

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So, these are various spacer as mentioned it earlier. A twin spacer, this is a quadruple spacer, four conductor – one, two, three, four conductor and different types of spacer. This is again a different types of spacer you have a vibration damper very important component which is fixed near the tower end you can see different this help in reducing the oscillations wake-induced or Aeolian type of oscillations in the transmission lines. So, the conductor is connected here both the sides help in reducing the low frequency oscillations. This is a spacer damper this acts as a 450 mm spacer plus it has a damping characteristics in its own. So, these are various accessories which are being used in high voltage transmission system.

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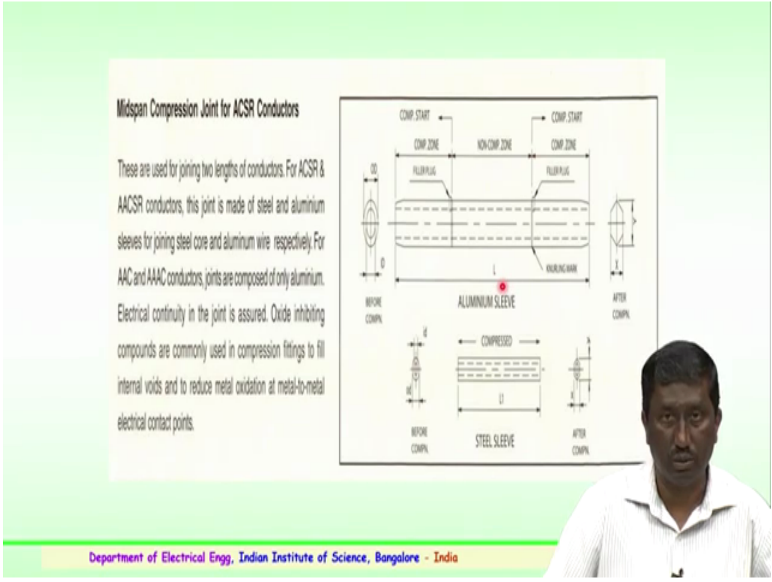

The details of the mid span compression joint which is used for various conductor will typically consists of aluminium sleeve having a filler plug at both the ends. And it has a compression zone and both the sides and non-compression zone. So, this non-compression zone will help in binding the conductors from both the ends which is used for joining two conductors for ACSR or any other type of conductors. This joint is made of steel and aluminium sleeves particularly for joining steel core and aluminium wire respectively. For AAC and triple AC conductor joints are composed of only aluminium electrical continuity in the joint is completely assured. Oxide inhibiting components are commonly used in compression fittings to fill internal voids and to reduce metal oxidation at a metal-to-metal electrical contact point, this is very important. So, the compressed joint has to take care of the electrical properties and see that the corrosion does not happen in the mid span from this is very important component of a transmission where it joints two lengths of the conductor in the transmission lines.

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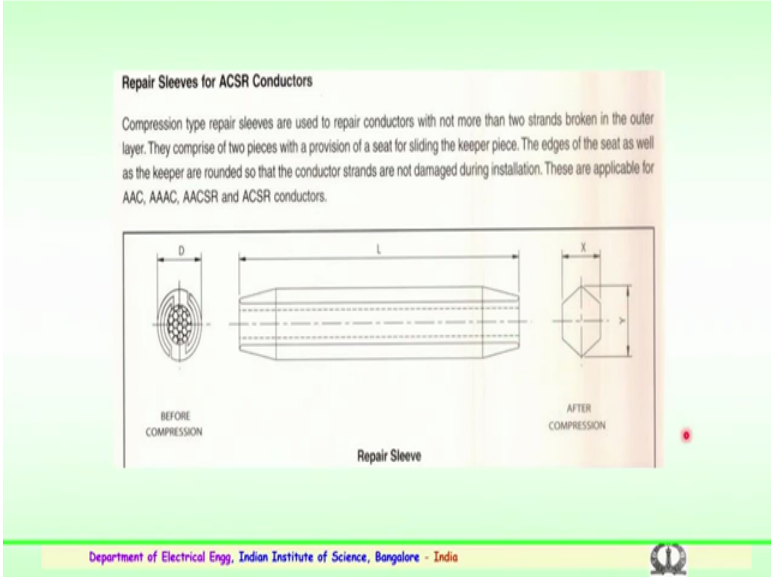

So, you have repair sleeve. Again the compression type repair sleeve are used to repair conductors with not more than two strands broken in the outer layer. So, they could see that the conductor has to be repaired. So, they have to compromise on two pieces with the provision of seat for sliding the keeper space you have a bottom space and top where the edges of the seat as well as the keeper are rounded, so that the conductor strands are not damaged during installation. These are applicable for all types of AAC, triple AC, ACSR, ACSR conductors.

So, this is before compression, this is the repair sleeve and this is the after the compression. Repair sleeve has shown earlier looks like this. This is the repair sleeve this is the mid span compression joint. So, repair sleeve, it is the slide, you can remove the top portion, insert the conductor again insert the top layer and crimp with the hydraulic pressure suitably defined for that particular conductor.

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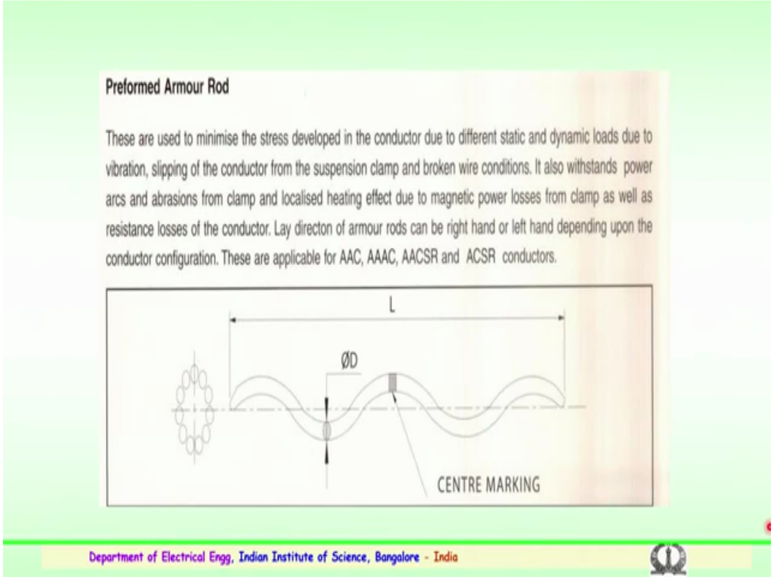

So, next is the performed armour rods. These are again very important armour rods are used to minimise the stress which is developed in outer conductor due to different static and dynamic loads because of vibration slipping of the conductor from the suspension clamp and broken wire conditions. This also withstands power arcs and abrasions from clamp and localized heating mainly due to magnetic power loss from the clamps as well as the resistance loss of the conductor. This lays the direction of armour rods can be right hand or towards the left hand depending upon the conductor configuration an either side of the insulation string. These are applicable for all types of conductors could be AAC, triple AC, AACSR and ACSR type of conductors.

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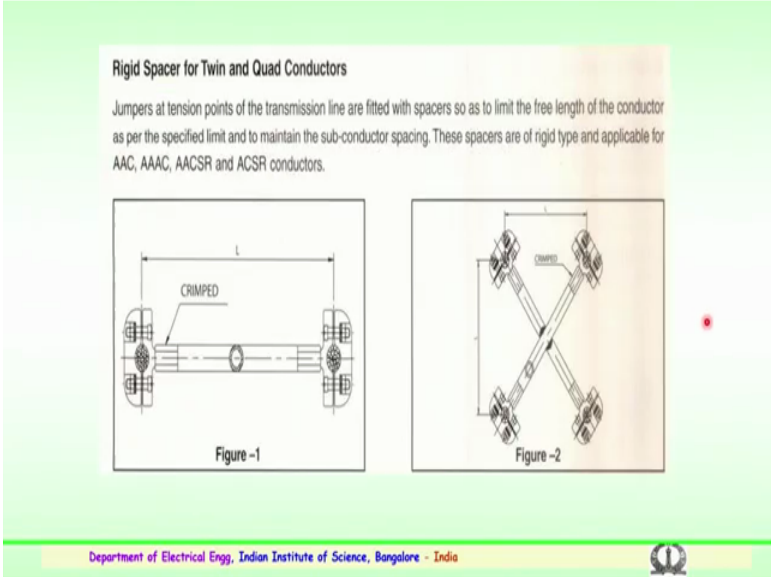

Then we have seen the rigid spacer both for a twin conductors and a quad conductors. The jumpers at tension point on the transmission are fitted with spacers. So, has to limit the free length of the conductor as specified limit in case for 45 centimeter to maintain the sub-conductor spacing in the country. These spacers are of rigid type and applicable for all the conductors AAC, triple AC, AACSR and ACSR conductors we have seen this spacers here again. So, these are the various spacers in case of quadruple conductors. So, rigid spacers for quadruple conductors are this

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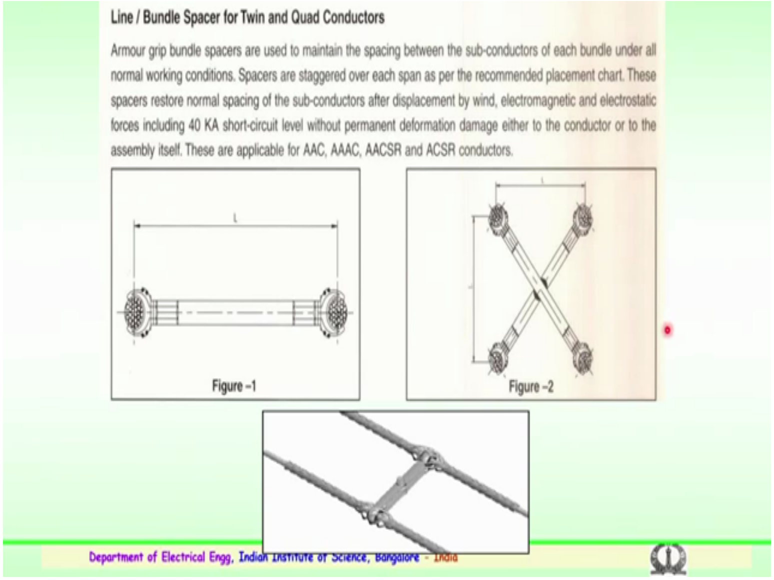

So, line or bundle spacers for twin and quadruple conductors similar spacing for 50 mm you have four conductors spacers that is a quadruple in case of two conductor, it is a twin type of conductor spacers. So, armour grip bundle spacers are used to maintain the spacing between the sub-conductors that is 45 centimeters in the country of each bundle under normal working conditions. And spacers are staggered over each span as per the recommendation placement chart, which is given as per the standard international standards of the manufacturers and to the utilities. These spacers restore normal spacing of the sub-conductor after displacement by wind. Electromagnetic and electrostatic forces including more than 40 kilo amp short circuit level without permanent deformation or damage either to the conductor or to the assembly itself these are again applicable to all types of conductors AAC, triple AC, AACSR and ACSR type conductors.

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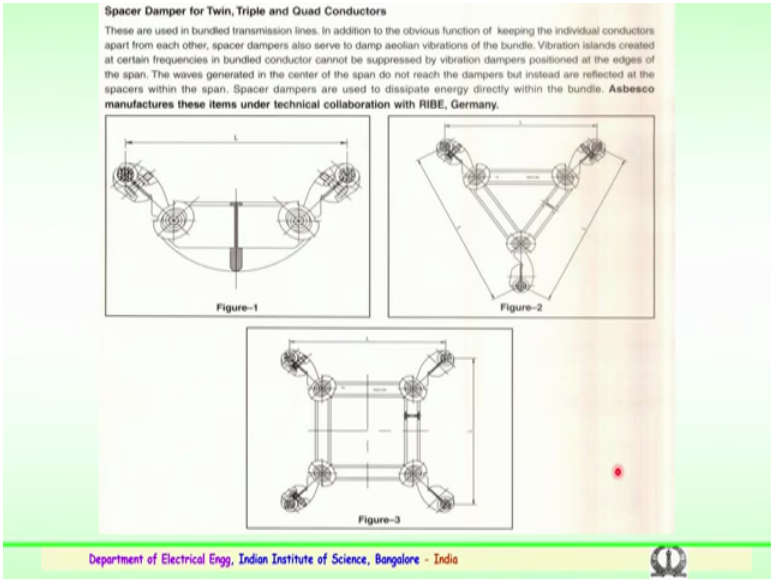

Important component the damper for twin, and triple and quadruple conductors. So, you have for two conductors this is the spacer damper; for three conductors, you have this type of conductors which are sixteen equilateral triangle type of arrangement. And for four conductor bundle, you have a square type of arrangements where four conductors are connected. So, this spacer damper is used for twin, or triple or a four conductor bundle and is used in bundle transmission lines in addition to the main function of keeping the individual conductors apart that is for 45 centimeters length apart from each other.

This spacer damper also serves to damp a Aeolian vibrations of the bundle that is inter bundle. Then vibrations islands created at certain frequencies in bundle conductor cannot be suppressed by vibration dampers positioned at the edges of the span. So, the waves which are generated in the centre of the span do not reach the dampers, but instead are reflected at the spacers within the span. So, at that instance, these spacer dampers are used to dissipate the energy directly with in the bundle and perform the functions.

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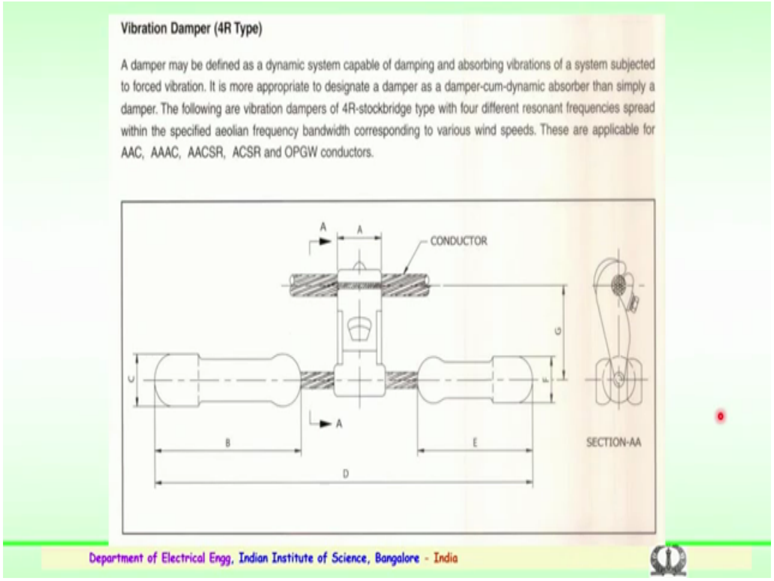

So, vibration damper important component that was of spacer damper. This is a vibration damper are there are different types. So, one is the 4R type of arrangement what is known as. A damper is normally defined as a dynamic system capable of damping and observing the vibrations, which are conductor sees in a transmission system and subjected to a forced vibration. So, it is more appropriate to designate a damper. As a damper come dynamic absorber then simply a damper that is very important.

Some of the vibration dampers with four different resonant frequencies spread with the specified Aeolian frequency bandwidth corresponds to various wind speeds. So, the damper will be tuned or will be able to suppress a four different type of frequencies which are seen in the vibration in the conductors because of the vibrations particularly due to the Aeolian vibrations. And the frequencies generated will be try to be suppressed with the help of this dampers. These again are applicable to all types of conductors which are being used and also to the earth wire. So, AAC conductors, ACSR and optical fibre, ground wire conductors also. So, the damper will be able to oscillate that. So, there is other two types of metal sections, the conductor is fixed here. So, each conductor will be connected to the vibration damper to see the vibrations are damped out.

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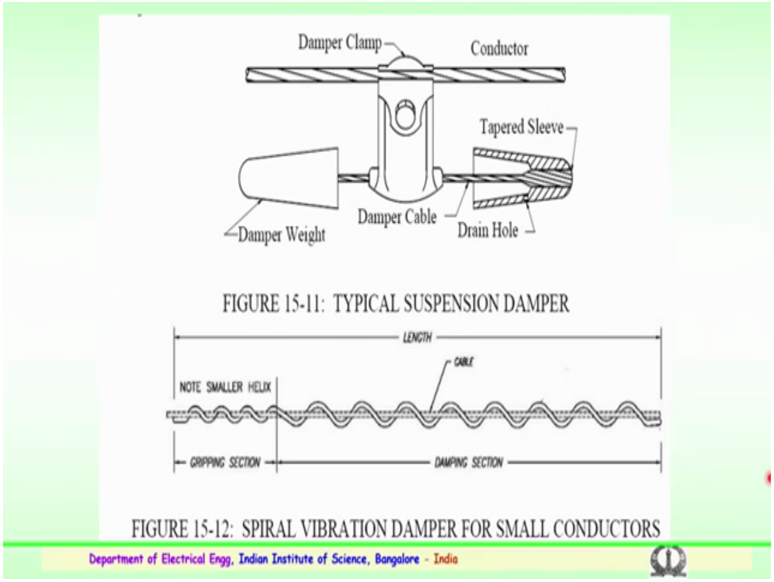

This is again a typical suspension type of a damper the conductor is here, the conductor the damper is made to fix on the conductor intentionally drain hole and a damper weight on both sides. And this sizes are a slightly different, they are not in equal weight. This is mainly to reduce the frequencies and to curtain the frequencies of four different frequencies with the conductor sees. So, this helps the proper containing the frequencies form due to the Aeolian and other vibrations.

These are the vibration dampers particularly for a very low voltage or a lower voltage single conductors spiral vibration dampers or the armour rods, which are being used near the tower for a single conductor will act as a damper for small conductor. And try to reduce the oscillations which are generated in the single conductor. So, very important component in the transmission apart from the mid span compression repair sleeve, the vibration damper plays a major role in containing the oscillations or the vibrations which the conductors sees in transmission or distribution system.

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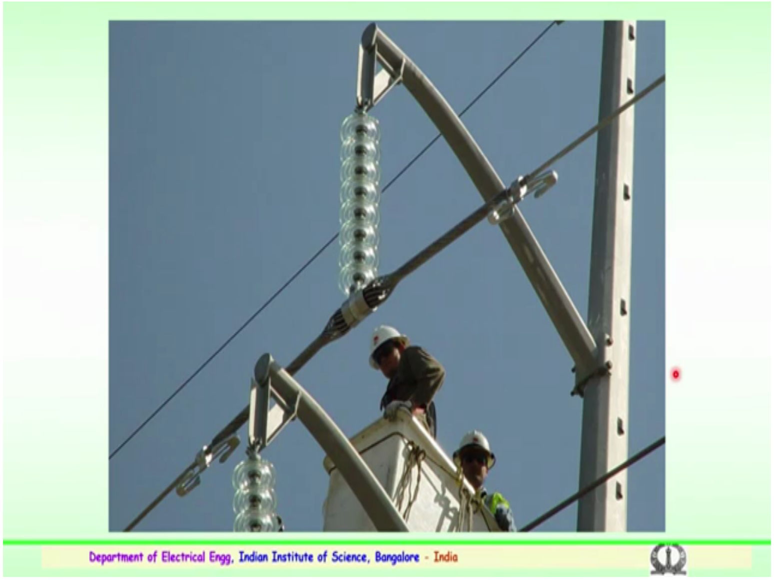

So, this is a typical arrangement with the armour type of conductors which are seen here. This will act as a damping arrangement. Further, you can see the damper here which is connected at both the ends of the conductor in case of Aeolian galloping or the wake-induced oscillations in case the tower or the conductor the conductor sees. This will try to reduce the oscillations or damps the vibrations, which are produced at low frequencies and sees that the further fatigue to the spacer conductor and also to the insulator string is being protected.

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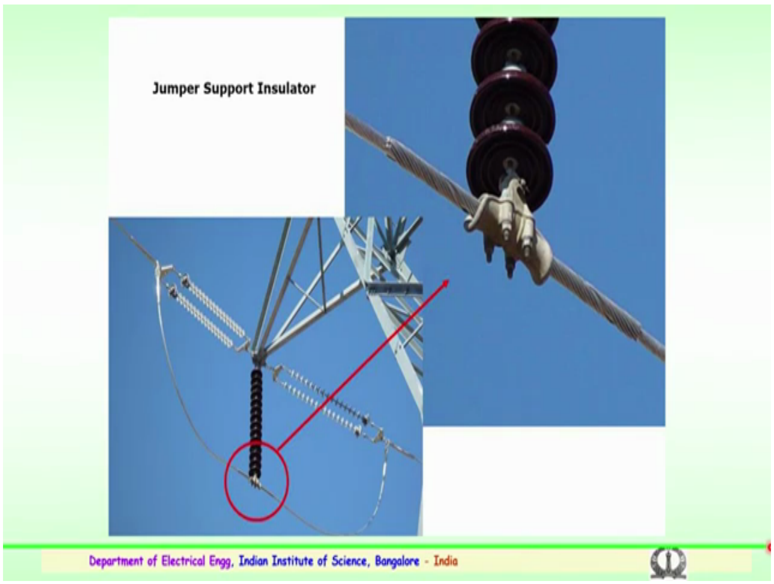

So, apart from the armour rods, this is for a single conductor to suppress the oscillations further a twin conductor four or eight conductor will have a damper arrangement. Usually for a single conductor near the insulator string, armour rods are fixed to see the damping of oscillations. Further in that area if the oscillations are seen the dampers could be also used. Apart from these the clamps or accessories very important the conductor clamps which are being used to connect the insulator and the clearances have to be maintained in case of a tower you have here example a twin tower, twin conductor insulator twin insulator string here. So, both the sides the conductors are connected.

To see the proper clearances from the tower suitable suspension insulator has to be used where the bypassed the conductor which is known as the jumper support to conduct the jumper support insulator is this suspension insulator and the jumper conductor has to be properly used to connect the either side of the conductor maintaining the clearances from the tower. So, this is a very important for the transmission utilities to maintain the clearances from the tower end metallic ends to the conductor. So, that is the reason where we use a suspension suitable suspension or suitable v-type of suspension arrangement to make necessary clearances and use a jumper support conductors of the same dimensions as the conductors.

So, these jumper type of arrangements could be twin conductor, again could be a quadruple conductor or a single or more number of a conductor depending upon the line that is a transmission line which is being connected. So, this again varies for the voltage levels.

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So, here you can see various type of accessories which are being used for the transmission e h v or UHV transmission. This typical tower shows you the double circuit line here you have one, two, three r y b is one circuit, and another two circuit have an insulator string. So, from the tower, you have a jumper type of arrangement here, you have a twin type of arrangement where the clearances have to be maintained; further to that in the transmission conductors, you see the jump vibration dampers which are fixed to each of the conductors.

So, in case of a four bundle conductor or four bundle spacer that is a quadruple spacer. Here you can see the quadruple spacer similar to a square type of arrangement distance maintained from conductor about typically 45 centimeters in case of India. So, a quadruple spacer is available and the dampers are connected to each of the conductors. So, this is how the conductor arrangements are been made for the e h v or UHV transmission near the tower ends. So, very important, so the insulators being a very important component of transmission system conductors are much more important accessories and hardware the tower and the foundations are equally important for UHV or e h v transmission.

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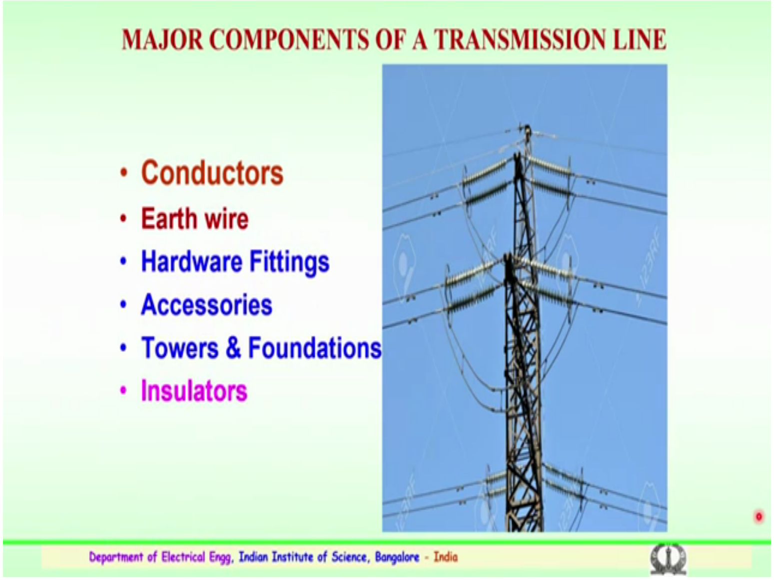

So, thank you, we will look the next class about the towers and the important foundations required for the e h v and UHV towers.

Thank you.