# STATE OF THE ART OF CONDUCTOR GALLOPING*

**A complementary document to "Transmission line reference book –Wind-induced conductor motion Chapter 4: Conductor galloping," Based on EPRI Research project 792**

**Task Force B2.11.06**
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**CIGRE ad hoc SC**

***Selected Sections of the Report***

*This information contained in this brochure is both up to date and comprehensive in its treatment of this important topic and will be valuable both to researchers, who are seeking to better understand the fundamental causes of galloping and Transmission Line engineers, who are faced with the practical consequences of galloping on their lines and need to find remedies. It will also compliment the revised EPRI 'Orange Book'*

## CAUSES OF GALLOPING

Galloping is a large amplitude (several metres), low frequency (fraction of Hz), wind-induced oscillation. In the vast majority of cases, an ice accretion is present on the conductor: this has the effect of modifying the conductor's cross-sectional shape such that it becomes aerodynamically and/or aeroelastically unstable [Blevins, 1990; Den Hartog, 1932; Edwards and Madeyski, 1956; Koutselos and Tunstall, 1988; Lilien and Ponthot, 1988; Lilien and Dubois, 1988; Nakamura, 1980; Nigol and Buchan, 1981; Rawlins and Pohlman, 1988; Richardson et al., 1963; Tunstall and Koutselos, 1988].

…Galloping is NOT a forced oscillation, it is a self-excited phenomenon. It may (and does) occur during both 'steady' and turbulent winds. The forced response of an overhead line to the turbulence of the natural wind (buffeting), which is not galloping, also occurs in the low frequency modes of conductor spans.

An aerodynamic instability can arise when the aerodynamic lift and drag acting on the iced conductor, as functions of angle of attack of the wind, provide a negative aerodynamic damping. This negative aerodynamic damping generally increases in magnitude as the wind velocity increases so that, at some critical velocity, the sum of the aerodynamic damping and mechanical damping in the conductor system becomes zero. Unstable motion can then develop, usually in the vertical direction [Den Hartog, 1932].

An aeroelastic instability is much more complex and will always involve more than one type of conductor motion (degree of freedom) - typically vertical and torsional motion - whereas an aerodynamic instability may involve only one. The aeroelastic instability is only possible because of a strong interaction between the aerodynamic properties of an iced conductor, as functions of angle of attack, and the structural properties of the iced conductor system. Bundled conductor systems are particularly susceptible to aeroelastic instability because their natural frequencies in vertical, horizontal and torsional motion tend to be very close together. This is true for any number of loops and there is no easy design means available for separating them. A change in effective angle of attack of the iced conductor - induced, for example, by vertical motion - leads to changes in all three aerodynamic forces (see Figure 4.4). Because of the close proximity of the natural frequencies in a bundle, the vertical motion is then readily coupled to horizontal and torsional motion. Of these, vertical-torsional coupling is usually the most significant and can lead to some spectacular galloping of conductor bundles

The gravitational moment provided by the eccentricity of the ice and the aerodynamic moment characteristic of an iced conductor can have a strong effect on the conductor's torsional stiffness - and, hence, torsional frequency. This can lead to a convergence of the vertical and torsional frequencies, even for single conductors where these frequencies are otherwise well separated. An aeroelastic instability may then ensue.

Galloping is NOT a forced oscillation, it is a self-excited phenomenon. It may (and do) occur, but not only, during constant wind.

The links between galloping and the two other main types of overhead line vibration - namely, aeolian vibration caused by vortex shedding and wake-induced oscillation in bundles - are very tenuous. All of these phenomena have their own physics and their own range of frequencies, galloping being associated with the lowest frequency range (typically, 0.1 to 1 Hz). Because the corresponding motion velocity of galloping is relatively low, the conversion of wind energy to conductor kinetic energy leads to the possibility of very high amplitudes. Amplitudes in excess of the conductor sag and, indeed, of 15 m peak-to-peak have been recorded.

Finally, it should be noted that most theoretical studies of galloping employ wind tunnel data that have been measured for winds perpendicular to the conductor axis. The complexity of fluid flow is such that these data may not be reliably used for studies involving non-perpendicular (yawed) winds by resolving the data into components perpendicular and longitudinal to the conductor.

## Factors influencing galloping

• ice accretion type and shape (eccentricity, weight, aerodynamic properties)
• wind velocity (with limited effects of turbulence and orientation as detailed)
• conductor self-damping (vertical, torsion) in the low frequency range (including span end-effects)
• span lengths (including all spans of a section) and section length
• longitudinal stiffness at attachment point on tension tower
• yoke plate assembly (tension and suspension tower) (torsional stiffness effect)
• number of subconductors and their arrangement
• subconductor spacing
• sagging conditions (effect on vertical frequencies)
• spacers (kind of spacer, location, eccentric weight effect, conductor constraint effect)
• presence of retrofit devices (all kinds including interphase methods)
• angular orientation of ice *in the presence of wind*
• ratio vertical/torsional frequency for each mode, *in the presence of wind*

## Field Testing

**In the field and laboratory observations.** Data on conductor galloping may be collected by three different means: By doing field observations on existing lines subjected to conductor galloping (see also section 2.5 Incidence of galloping); by reproducing conditions propitious to conductor galloping using artificial ice shapes on a full scale test line, or; by characterizing aerodynamically different ice shapes through wind tunnel measurements and determine the cable response using a mathematical model.
Tests of galloping behavior in full-scale spans exposed to natural winds are normally directed at improved understanding of the phenomenon, at testing theories of galloping or at evaluation of proposed protection schemes. Certain test programs are carried out on spans fitted with artificial ice of some shape. Others are organized on spans of operating lines on which icing is anticipated.

**Observations, Measurements, and Recordings.** The procedures employed in conducting tests on spans fitted with artificial ice vary with the purpose of the test and the productivity of the span. Some testing employs simple visual observation for acquiring data. Amplitudes are estimated with reference to known line dimensions, frequencies are timed with a watch, and wind is measured with hand-held anemometers. More often, suitably chosen transducers and recording systems are employed.

Conductor motions have been sensed by attaching a string to the conductor, the string being supplied from spring-loaded reels at ground level. A multiturn potentiometer coupled to the reel shaft makes an electrical signal representing vertical amplitude available for recording. <u>This method was developed by A. S. Richardson and was utilized by Alcoa Laboratories</u>. [emphasis added]

Accelerometers have also been used for sensing vertical, horizontal and torsional amplitudes [Edwards and Madeyski, 1956; Nigol and Clarke, 1974]. The conductor displacement along the span may be inferred from two accelerometers signals [Van Dyke et al., 2006]. Bending amplitude recorders of the type normally utilized in aeolian vibration testing have been applied on occasion for galloping recording. It should be noted that some of these bending amplitude recorders have a lower limit to the range of frequencies recorded, which may preclude their registering normal galloping motions.

The amplitude of galloping, or its severity, can be inferred from support point load variations and insulator string deflections if conductor tension is known. Clinometers may be added on the insulator string of suspension towers to calculate the components of force transmitted to the tower

**Methods for Protection and Galloping Control.** We reproduce here the conclusions:

• The complexity of galloping is such that control techniques cannot be adequately tested in the laboratory and must be evaluated in the field on trial lines. This testing takes years and may be inconclusive.

• Analytical tools and field test lines with artificial ice are useful in evaluation of galloping risk and appropriate design methods.

• No control method can guarantee it will prevent galloping under all conditions.

• Interphase spacers virtually ensure galloping faults will not occur, but do not necessarily prevent galloping. Their usage is growing and their design is undergoing further development.

• Mechanical dampers to stop vertical motion are still being pursued but to only a very limited extent.

• Torsional devices, which either detune or increase torsional damping or both, are being pursued and actively evaluated.

• Techniques which disrupt either the uniformity of ice accretion by presenting a varying conductor cross-section or the uniformity of the aerodynamics by inducing conductor rotation are being actively pursued.

• Methods of ice removal or prevention are not widely used as specific anti-galloping practices.

• Despacering or using rotating-clamp spacers is still used extensively in a number of parts of Europe subject to wet snow accretions.

• For bundled conductors, the influence of the design of suspension and anchoring dead-end arrangements on the torsional characteristics of the bundle and on the occurrence of vertical/torsional flutter type galloping has been recognized.

## Galloping control methods for existing lines

A survey of the various known galloping control methods was recently completed under the aegis of CIGRE and published in ELECTRA [Cigre, 2000b]. The various control approaches were classified as “retrofit” or “design” systems. This chapter will provide descriptions of “retrofit” devices. The ELECTRA paper also includes a list of discontinued methods. This chapter will focus on control devices which are considered to be practical, and in use, at least on a trial basis, on operating lines. Whenever possible, practical issues relating to ease of installation and side effects attributable to the devices will be summarized.

### *Interphase Spacers*

Field trials of interphase spacers were in place on Ontario Hydro lines during the 1970s [Pon et al., 1982]. In that period a number of manufacturers’ products were installed, and most of the installations were on single conductor lines with stiff spacers. The field results from single conductor lines only are presented in summary form in Table 8.1.

The field data from single conductors shows, on average, a reduction in the reported galloping amplitudes, but there are still large amplitudes of motion on the lines with interphase spacers.

<u>The maximum amplitude is reduced from 0.52 x sag to 0.38 x sag, a reduction of 27%.</u> [emphasis added]

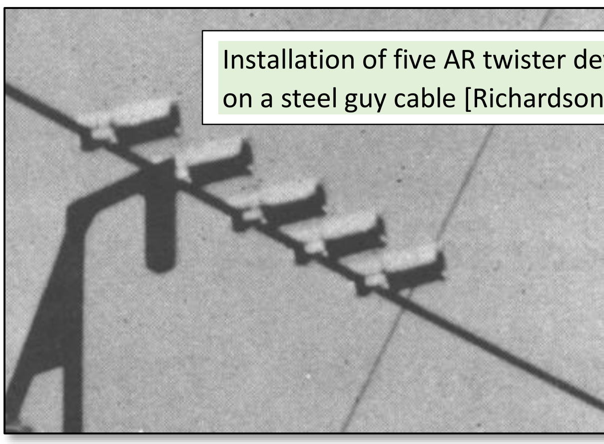
In summary, the interphase spacers have a good track record for eliminating flashovers during galloping but they do not prevent the galloping motions. Observations in the field show that motions still occur with interphase spacers in place, especially when the galloping conditions are such that high levels of motion can occur. The side effects of galloping such as high loads on the support structures and damage to the conductors at the suspension clamps can still be a problem with interphase spacers. Interphase spacers are also subject to breakage if they are not designed well enough for the dynamic loads applied to them.

### *Aerodynamic control devices*

Galloping may be reduced when the ice profile is smooth and less eccentric. This review includes devices that are designed to encourage oscillation of the conductor during an ice storm to create a smoother ice profile with lower level of aerodynamic lift and moment.

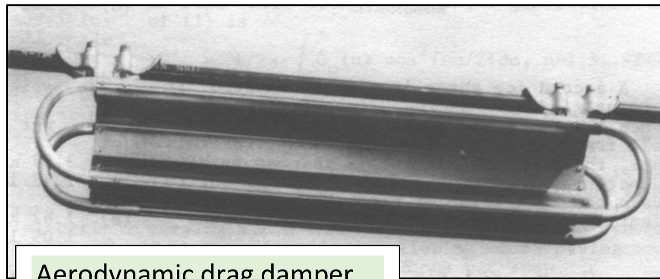
**Rotating clamp spacers** allow the subconductors of the bundle to rotate and behave more closely to single conductors, which do not gallop as frequently as bundled conductors in Japan. This behavior is characteristic of regions where wet snow is more common than glaze ice. The eccentric weights are about 20 kg, and are mounted horizontally in alternating directions on the subconductors, and then any galloping motions that occur twist the weights around the subconductors and a smooth ice profile with lower aerodynamic lift is created. The system of rotating clamp spacers and eccentric weights has also been applied to quad bundles.

**AR Twister.** Based on the principle of creating a smooth ice profile, but for single conductors, is the AR Twister [Richardson, 1989]. This device is a weight attached rigidly to the conductor by a standard conductor clamp. The individual weights are about 3.6 kg (8 lb). The AR Twister is installed vertically above the conductor at mid-span, and the total weight and number of devices is chosen to rotate the conductor through between 90 and 140 degrees. During galloping the rotational oscillations are enhanced, so that the ice deposit forms on a greater area of the conductor, and a smoother profile is obtained. The aerodynamic lift is thereby reduced and galloping is less likely to occur.



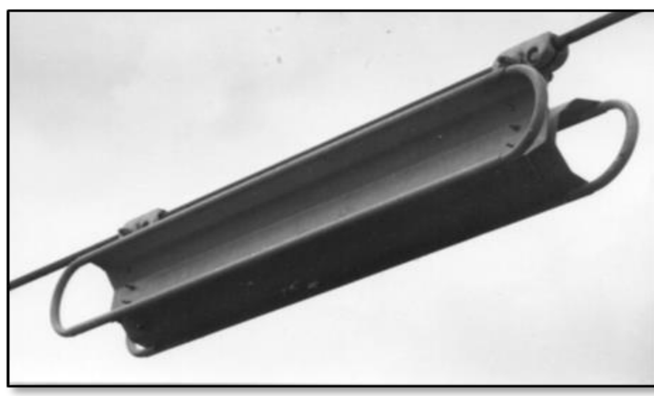
Installation of five AR twister devices on a steel guy cable [Richardson, 1989]

**AR Windamper.** The final aerodynamically based device, the AR Windamper, employs smoothing the ice profile and increasing both aerodynamic drag and the aerodynamic damping of the conductor. It is similar in some ways to the aerodynamic tee foil, which was used on distribution lines in the CEA field trials, but was also originally intended for use on larger conductors [Liberman, 1974]. The AR Windamper, is designed to provide a rocking motion due to the wind to create the smooth ice shape, and through its increase of area to the wind, adding aerodynamic drag and damping [Richardson, 1979]. There are versions for lower voltage lines, without the corona reducing end treatments, shown in the figure.



Aerodynamic drag damper [Richardson 1979]

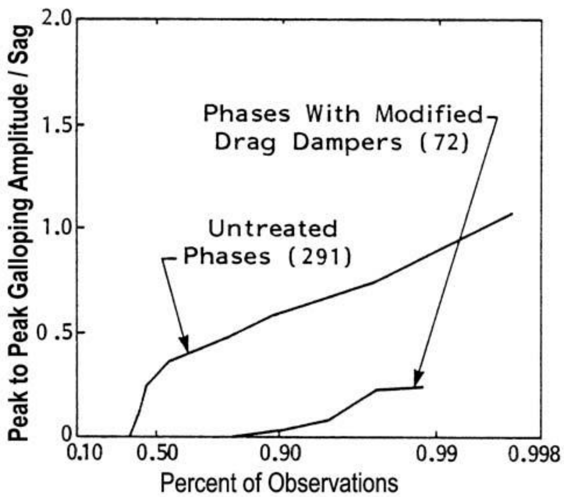
The Windamper was investigated at Ontario Hydro and subjected to analytical studies, and wind tunnel modeling. As well as confirming the available drag and damping effects, the findings included the discovery that under high winds the device would swing away from the vertical position and become aerodynamically unstable. These studies led to the name “modified drag damper” or MDD. To stabilize the behavior under high wind, the addition of a second, heavier and geometrically similar, device was suggested for each span. This version of the Windamper was installed with both heavy (45 kg or 100 lb.) and light (14 kg or 30 lb) designs in each span, and this control system was included in the field trials conducted on Ontario Hydro’s operating lines.



The field trials that followed used at least two devices of different weights in each span. The devices were evaluated under galloping conditions on single and bundle operating lines in the same manner as the devices described earlier.

The effectiveness was measured by comparing the peak-to-peak amplitudes of motion on nominally identical untreated conductors with those on the conductors with the Windamper|MDDs in the same span.

The results obtained on single conductors after eight galloping events are summarized below. This plot uses the field data from every individual span of conductor recorded, as opposed to averages on the treated and untreated phases, which is statistically more valid. The peak-to-peak galloping amplitudes are divided by the sag to provide comparisons of spans of different lengths and with standard clearance ellipse design procedures. The plot indicates that the Windamper|MDD reduced the maximum amplitudes from 0.85 times to sag to 0.22 times the sag. This is an improvement of about 75 percent. [emphasis added]




Observed amplitudes of galloping normalized by dividing by sag, on untreated single conductors and single conductors with modified drag dampers during 8 galloping events [Havard and Pohlman, 1981]

## Cautions to be observed when applying in-span galloping control devices

In-span hardware, including galloping control devices and aircraft warning markers, are concentrated masses, which can act as reflection points of traveling waves of aeolian vibration. This vibration due to wind can occur in the sections of the conductors or overhead ground wires between the in-span devices and these sections of the span are isolated from any vibration damping systems, which are most often applied to the ends of spans. For spans of conductors with low tension this does not cause any problems. However extra precautions are needed for spans with tensions approaching the safe tension limits with no dampers [CIGRE, 1999]. The precautions required are to reduce the stress concentrations at the metal clamps attaching the hardware to the conductors. Two alternatives for reducing these stresses are installing armor rods under the metal clamps or replacing the metal clamps with elastomer lined clamps [Van Dyke et al., 1995]. A further option is to add vibration dampers within each subspan between the in-span hardware.

A second aspect requiring caution applies to galloping control devices based on the control of torsional motions. These are custom designed based on the parameters of the conductor span. They are designed to ensure that the torsional natural frequency, after adding the devices and a chosen amount of ice and wind, falls within a range necessary for the proper function of the control device. The caution required for this is that the actual parameters of the line need to be known, and that may necessitate a line survey to confirm that the line is installed according to the design. In particular the tension of the conductors has been found to deviate from the as designed values, especially in regions where ice loads have occurred increasing the sag, or where repairs have been made in the spans. There are ratios of torsional to vertical oscillation frequency that make a span more likely to gallop. Consequently, it is possible to misapply the devices if they are designed with the wrong input parameters, or if the resonant behavior is not avoided by proper choice of device dimensions. It is therefore highly recommended that the design of galloping controls be carried out by experienced practitioners.

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