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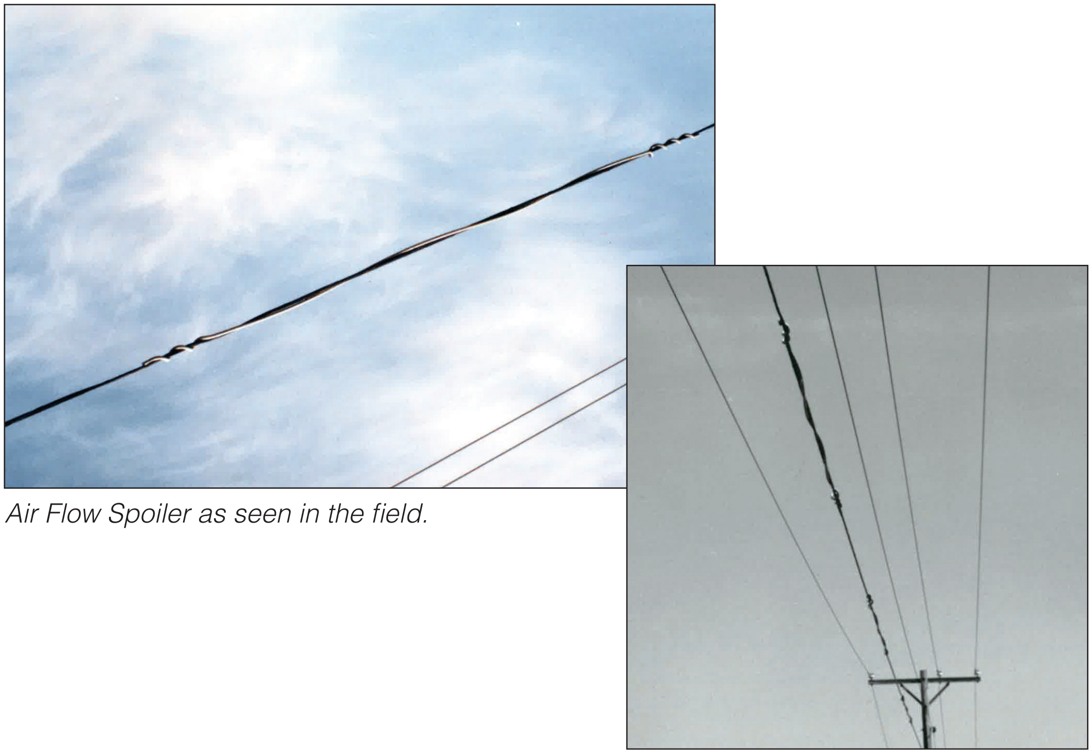
Conductor Galloping Basics

February 2016

Part of a series of reference reports prepared by
Preformed Line Products



Air Flow Spoiler as seen in the field.

Conductor Galloping Basics

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INTRODUCTION TO GALLOPING

Galloping is the spectacular vertical motion that can occur in winter due to wind action on conductors with a layer of ice or wet snow. It can affect all types of conductors and overhead ground wires, used in overhead distribution and transmission lines. It affects both single and bundled conductors. Galloping occurs when a conductor (or cable) presents an asymmetric profile to a moderate to high wind flow. Typically the wind flow is in excess of 15 mph. When transverse winds impact an ice or wet snow covered overhead power line, the conductors can undergo the large amplitude, low frequency, quasi-vertical motions called galloping. Severe galloping can cause phase-to-phase and phase-to overhead ground wire contacts, flashovers, and interruptions of the power flow. (Havard, D. G., 2003) In addition, the large amplitude, low frequency galloping can produce dynamic loads sufficient in number and magnitude to loosen bolts, break insulators, damage or misplace vibration dampers and other hardware, break tower bracings, and even cause failures of tower legs. (Havard, D. G., 2003) The resulting conductor burns require repairs, and the loss of capability to transmit power due to failed conductor or hardware can be very costly to the power utilities. (Havard, D. G., 2003).

MECHANISMS OF GALLOPING

Galloping is a low frequency (from 0.1 to 1 Hz), large amplitude (from +/- 0.1 to +/- 1 times the sag of the span or up to 12 meters or 40 feet) wind induced, predominately vertical, oscillation that can occur on both single and bundled conductors. The galloping motions generally require an accretion to create an asymmetric cross section of the conductor.

When wind blows on a span of conductor, it swings away from the vertical position and due to the variations in wind speed the span will gently oscillate about some mean position. When there is an accretion, the conductor will also roll under the same winds due to the displacement of the center of mass and center of pressure from the elastic center of the conductor. The rolling action will oscillate at the torsional natural frequency. As ice builds up, mainly on the top and windward side of the conductor, the torsional natural frequency reduces and when that frequency approaches one of the lower odd numbered vertical natural frequencies, galloping can ensue. (Nigol, O. and Clarke, G. J., 1974). Galloping also requires fairly steady winds transverse to the conductor, and the amplitude of motion will increase in response to the increase in wind speed and associated wind energy. The aerodynamic forces and mass effects also increase with the thickness of the ice layer (Figure 1).

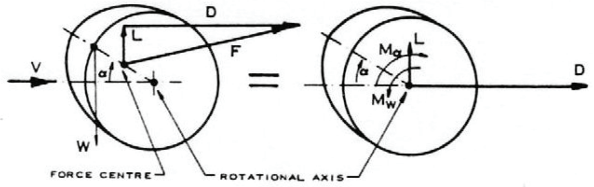


Figure 1: Wind and weight forces acting on an iced conductor (Nigol, O. and Clarke, G. J., 1974).

The mode of the motion is one or two, and sometimes three or four, half waves in the span. If galloping is not controlled, conductors in vertical circuits can come into repeated contact with each other and flashover–causing burns of the outer strands of conductors and over loading of the terminal equipment. Usually circuits have to be disconnected to prevent equipment damage.

Figure 2 shows that when the angle of attack α is around 45 degrees, the lift curve is at a maximum and the wind can impart an upward force on the conductor, such that it will act like an airplane wing, and the effective weight will be reduced and allow the conductor to float upwards. When the conductor twists, the forces are reversed and the wind force acts downward, leading to the growth of the vertical motion during galloping. This is evident in films of galloping motion when the vertical and torsional

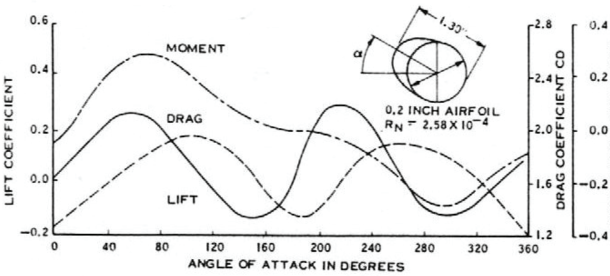


Figure 2: Aerodynamic lift, drag and moment forces on a conductor with a crescent shaped airfoil (Nigol, O. and Clarke, G. J., 1974).

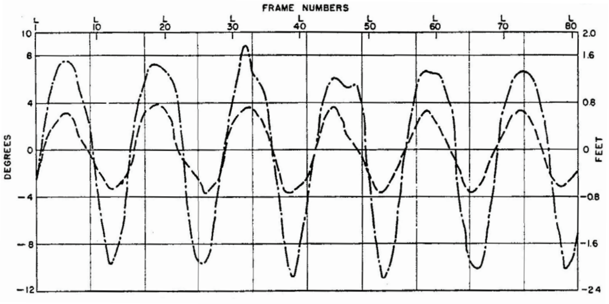


Figure 3: Movie Film Analysis of Single Loop Galloping Motion of a Single Conductor
- - - - - Vertical
- . - . - Torsional
Horizontal Scale 0.5 Sec. Intervals ((Edwards, A. T. and Madeyski, A., 1956).

motions are tracked against time. See Figure 3 (Edwards, A. T. and Madeyski, A., 1956). Films of bundle conductors during galloping show spacer motions, which demonstrate the same synchronization of vertical and torsional motion.

The galloping motion of the conductor can be seen as standing waves or traveling waves or a combination of both. The standing waves consist of forced nodes at the support structure and intermediate nodes spaced along the span at intervals that depend on the particular natural frequencies at which the conductor is vibrating (Figure 4).

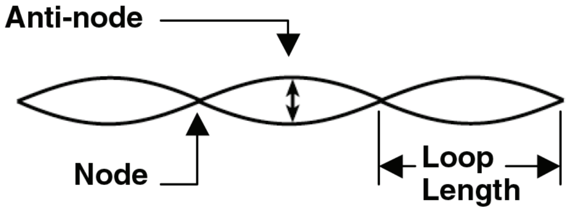


Figure 4: Galloping Standing Waves

The natural frequencies at which a conductor will vibrate in a series of standing waves can be approximated by the following:

Frequency (Hertz) = $\mathbf{(Tg / W)^{1/2}}$ **x** $\mathbf{(n / 2S)}$
– where:

T is Conductor Tension in Pounds
g is 32.2 ft / sec^2 (Gravitational Acceleration)
W is Conductor Weight in Pounds / Foot
S is the Span Length in Feet
n is the Number of Standing Wave Loops in the Span

	Natural	Loop
N	**Freq**	**Length**
1	0.2	800'
2	0.5	400'
3	0.7	267'

Table 1:
Natural Frequencies and Loop Length of Drake Conductor

For an 800 foot span of 795 kcmil ACSR 26/7 Drake conductor, the frequencies and loop lengths of galloping for a tension of 15% of RBS (4725 lbs) are shown in Table 1.

Galloping has typically been recorded as single, double and triple standing waves (Figure 5). When a suspension span gallops in one or three (but not two) loop mode, the insulator strings oscillate along the line and high dynamic loads are imparted to the insulator, suspension hardware and tower arms. These dynamic loads can exceed the static tension in the conductors.

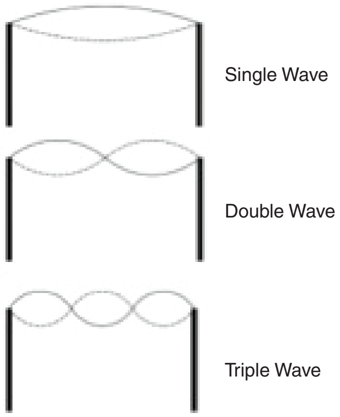


Figure 5: Galloping Standing Waves

HOW THEY WORK

AIR FLOW SPOILERS

Preformed Line Products (PLP) introduced Air Flow Spoilers in the early 1980's as a means to mitigate galloping of conductors. When a freezing rain or snow event occurs, there is snow or ice build-up on the conductor. In many cases, this build-up is uniform along the length of the conductor (Figure 6B). By placing an Air Flow Spoiler on the conductor, the spoiling section of the Air Flow Spoiler creates ice buildup profiles that vary along the length of the conductor (Figure 6A). These varying profiles create balancing alternate upward and downward air pressures, for the wind flow, thus creating overall resisting net vertical wind forces which eliminate or greatly reduce the level of galloping.

Over a 4 year period prior to market introduction, field studies were conducted utilizing the Air Flow Spoilers to determine the appropriate spoiler diameter and span coverage to minimize galloping. The Air Flow Spoiler are most effective when they are placed on 25% of the span length (based on a spoiling length of 12'). For example, for an Air Flow Spoiler with a 12' spoiling length, a 600' span would require 13 Air Flow Spoilers [(0.25X600)/12]. The Air Flow Spoilers are grouped in the middle 50% of the span by leaving a blank space equal to an Air Flow Spoiler length between adjacent units. To demonstrate the placement of Air Flow Spoilers, there are 2 scenarios to consider: an even number of Air Flow Spoilers in which the center span is untreated and an odd number of Air Flow Spoilers in which the center of the span is treated. For a span of 100 feet that requires two Air Flow Spoilers that are 15 feet in length, find the center of the span, leave the 15 feet at the center empty and apply Air Flow Spoilers on each side of the empty center space until the required number of Air Flow Spoilers has been installed (Figure 7).

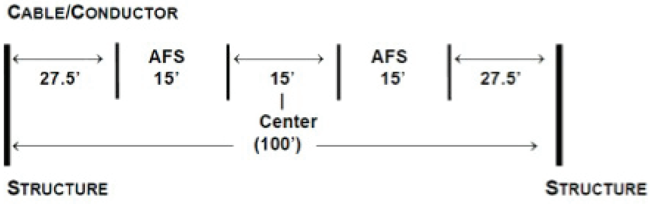


Figure 7: Even Number of Air Flow Spoiler Spacing

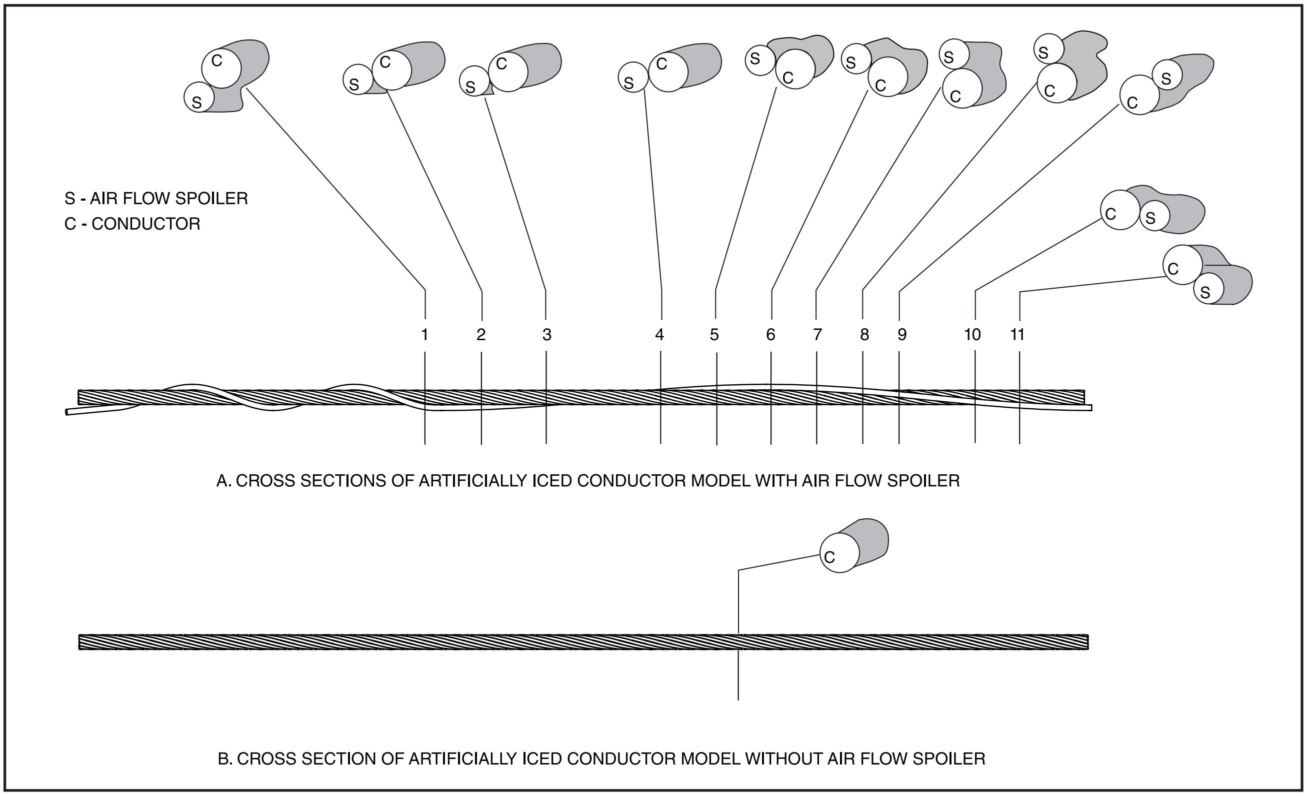


Figure 6: Ice Build-up on Conductor with (A) and without (B) an Air Flow Spoiler

For a span of 150 feet that requires 3 Air Flow Spoilers that are 15 feet in length, find the center of the span, apply the first Air Flow Spoiler and then apply additional air flow until the required number of Air Flow Spoilers have been installed (Figure 8).

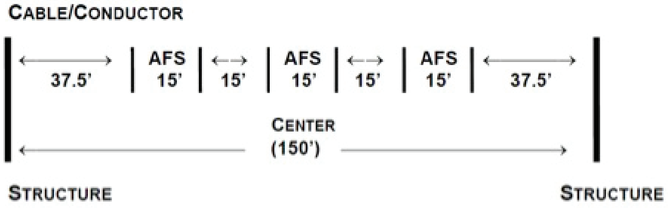


Figure 8: Odd Number of Air Flow Spoiler Spacing

Air Flow Spoilers are constructed of a resilient polyvinyl chloride material that can withstand the impact of UV and temperature. The main features of the Air Flow Spoiler are (Figure 9):

- **Gripping Section:** Grips cable – consists of several pitches (360° wraps around the cable) and holds the Air Flow Spoiler firmly in position.

- **Application Support Helix:** Supports Spoiler. Air Flow Spoilers range in length from 14 to 16 feet. The Application Support Helix on one end keeps the Air Flow Spoiler from hanging down, while the gripping section on the opposite end is applied.

- **Spoiling Section:** Disrupts the aerodynamic lift. The spoiling section is wrapped around the cable either two or three times, depending on the cable diameter.

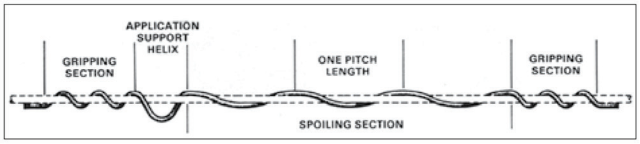


Figure 9: Air Flow Spoiler

The Air Flow Spoiler can also be supplied for EHV applications. The EHV Air Flow Spoiler incorporates a co-extruded semi-conductive outer layer of material, which resists the surface effects of high electrical gradients and minimizes the possible generation of radio interference.

For applications which require temperatures above 125° C and up to 250° C, PLP has a specially designed High-Temperature Air Flow Spoiler. This design utilizes preformed aluminum rods which are subset into groups of 3 or 4 wires. The spoiling section of the wires is cabled (twisted together) to achieve an effective diameter that is equivalent to the standard Air Flow Spoiler and the spoiling section is slightly longer than the standard Air Flow Spoiler. The high temperature Air Flow Spoiler can be used on ACSS and composite core conductors such as ACCR and ACCC. Contact PLP for additional information on the family of Air Flow Spoiler products.

DETUNING PENDULUMS

Detuning Pendulums were introduced in the 1970's as a result of extensive laboratory and field research. In 2015, PLP reached an agreement with Thomas Sherman and D. G. Havard to transfer the technology to PLP.

A widely accepted explanation of the galloping mechanism is the torsional theory of Nigel and Clark developed in the 1970's. According to this theory, the wind excites a torsional natural frequency of the iced conductor which in turn excites a close vertical natural frequency with galloping as a result. When an asymmetric coating is present on a conductor and wind is blowing, lift and drag forces exist. These 2 aerodynamic forces are effectively applied on a point inside the conductor, which is called the aerodynamic center, which is not the center of the conductor (Figure 10) (EPRI Chapter 4 Galloping). The moment due to ice buildup and the wind force on the conductor change both the vertical and torsional frequencies of the conductor. The vertical frequency

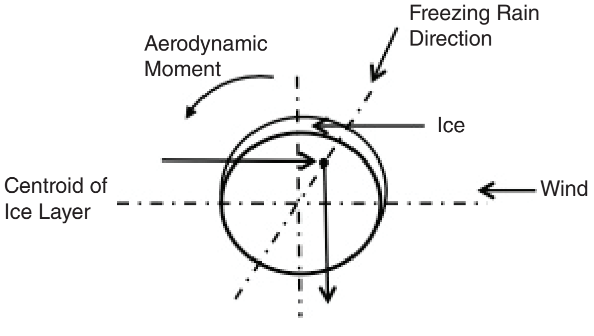


Figure 10: Loads on an ice covered conductor (Havard 1979)

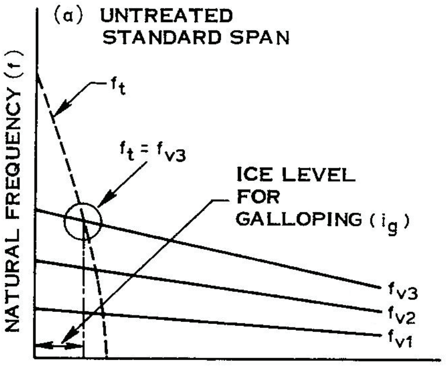


Figure 11: Torsional and Natural Frequencies of Ice, (Havard, D. G. 1979).

gradually drops as the moment due to the ice and wind build up. The torsional frequency drops more rapidly with the ice and wind moment and at some point the torsional and vertical frequencies approach and coincide (Figure 11), resulting in galloping.

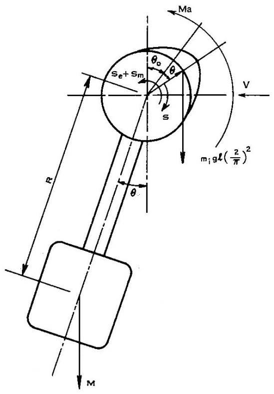


Figure 12: Load on conductor with detuning pendulum applied (Nigol and Havard, 1978).

When a Torsional Detuning Pendulum is attached to the conductor, the pendulum moment opposes the wind and ice moment (Figure 12). The torsional frequency is therefore controlled by the Detuning Pendulum arm length and the torsional frequency stays close to the torsional frequency value with no ice until a much larger ice and wind moment is present (Figure 13). The level at which the ice and wind moment will initiate galloping is controlled by the length of the detuning pendulum arm and the detuning pendulum weight.

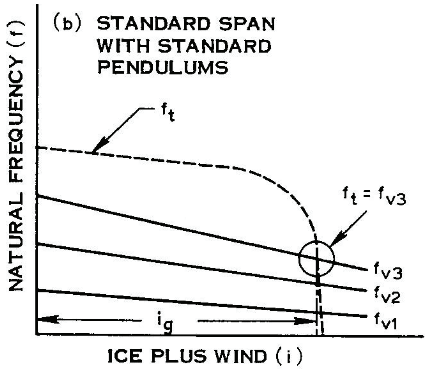


Figure 13: Torsional and Natural Frequencies of ice covered conductor with detuning pendulum applied (Havard, D. G., 1979).

Detuning Pendulums are composed of a frame metal construction. The main features of the Detuning Pendulum are (Figure 14):

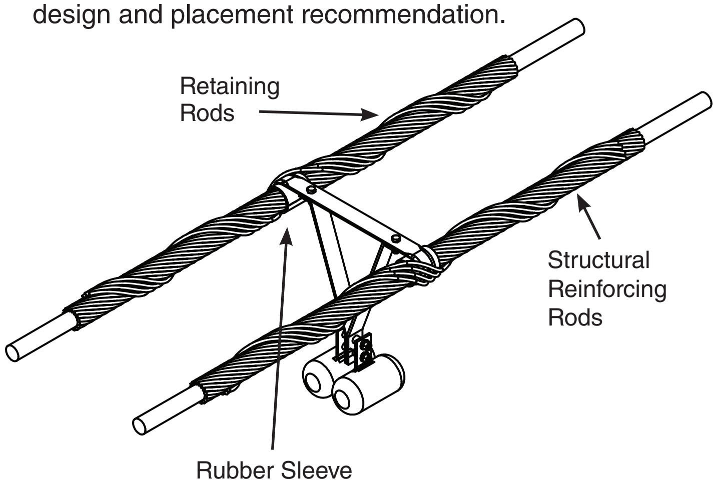
- **Structural Reinforcing Rods:** Protect conductor. Armor rods are applied to the conductor before placing the Torsional Detuning Pendulum in order to protect the outer aluminum strands from damage due to increased stress at the attachment location.

- **Rubber Sleeve:** Protect armor rods. The rubber sleeve provides an added layer of protection to the armor rods where the Torsion Detuning Pendulum is placed on the armor rods.

- **Retaining Rods:** Secure Detuning Pendulum. Helical rods are used to attach the Detuning Pendulum to the conductor. Helical rods reduce the level of strain to the armor rods at the attachment point.

- **Detuning Pendulum Moment Arm and Weight**: Arm length and weight required to overcome moment of ice and wind load, thus minimizing or eliminating galloping.

Typical arm lengths are between 9 and 18 inches, and typical weights are between 25 and 75 pounds. Usually there are four pendulums, unequally spaced, across average spans. Placement and design of the Detuning Pendulums is line specific and requires analysis. Please contact PLP for a full analysis, design and placement recommendation.



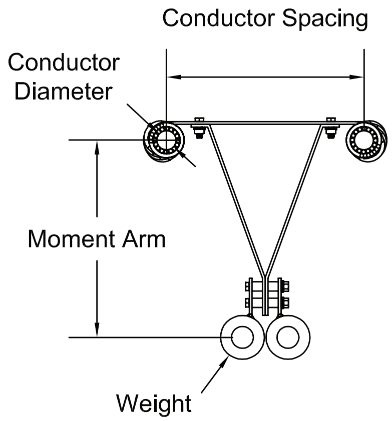


Figure 14: Detuning Pendulum

EFFECTS OF GALLOPING

Due to the large amplitude nature of galloping, there are multiple key effects on transmission lines as a result of this phenomena. The first is possible flashover resulting from phase to phase contact created by the large amplitude displacements. Phase to Phase contact between conductors can cause severe burns and damage to the individual wires of the conductor (Figures 15 and 16).

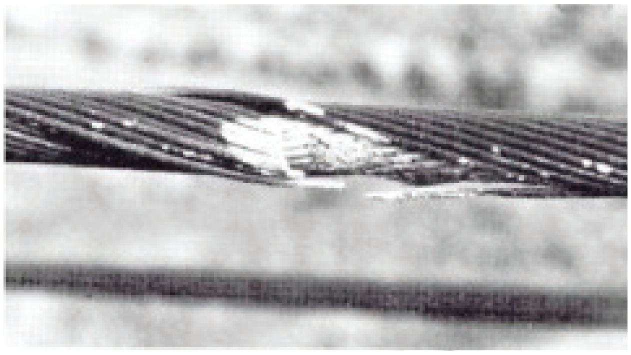


Figure 15: Conductor damage due to flashover (Leppers, P. H., 1981).

Figure 16: Conductor Damage due to flashover (Leppers, P. H., 1981).

Another is conductor fatigue damage at suspension attachments points and attachment points of other associated hardware (Figures 17 and 18). These are a result of the larger dynamic strains that are imparted on conductor as a result of the larger bending stress at the attachment points.

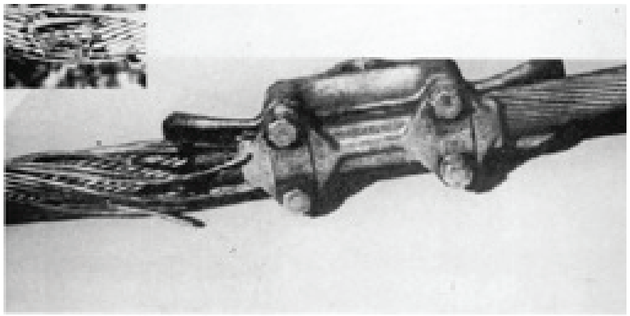


Figure 17: Conductor damage at clamp (Leppers, P. H. and Wijker, W. J.,1979).

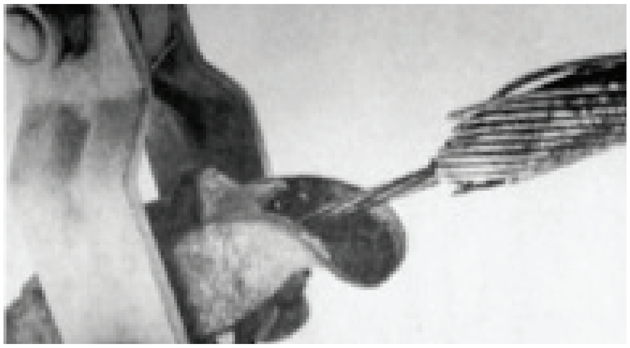


Figure 18: Conductor damage at clamp (Leppers, P. H., 1979).

Finally, there can be significant damage to the associated suspension hardware and structures as a result of the large dynamic loads (Figures 19, 20, 21 and 22).

Figure 19: Structure damage due to galloping

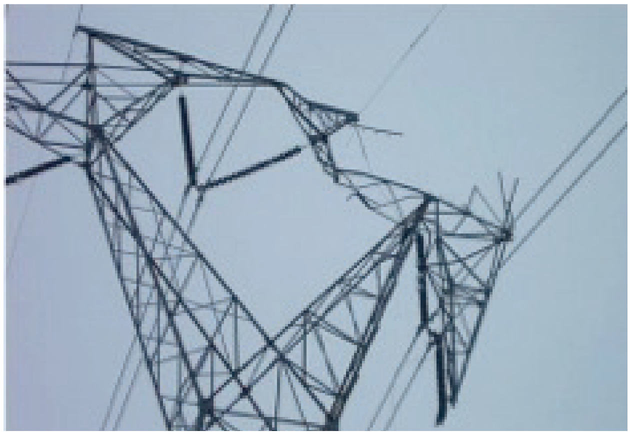


Figure 20: Structure damage due to galloping

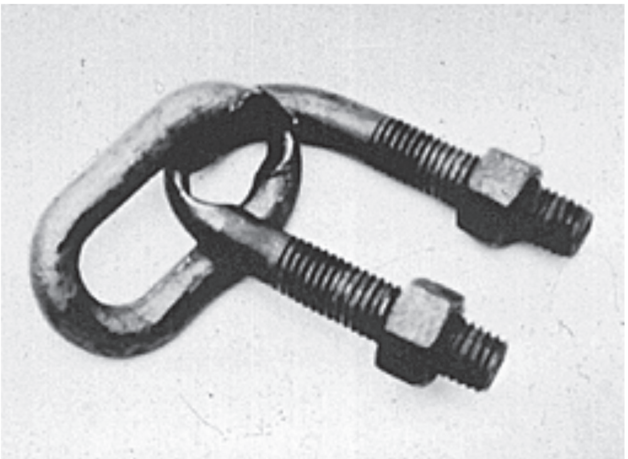


Figure 21: U-bolt and chain link damage due to galloping

Figure 22: Suspension housing damage due to galloping

FIELD TESTING

The effectiveness of both of both the Air Flow Spoiler and the Detuning Pendulums has been extensively monitored and proven on operating lines under a range of extreme weather condition during a 15 year period from 1970's through the late 1980's.

Figures 23 and 24 shows the typical results of field observations and demonstrate the effectiveness of both devices in reducing and eliminating galloping. Both devices reduce the number of galloping occurrences and when the galloping is not fully eliminated, the amplitudes of motion are less than about one third of those on untreated lines.

The data that is represented in Figures 23 and 24 is from 31 individual galloping events using Air Flow Spoilers and 99 individual galloping events using Detuning Pendulums respectively.

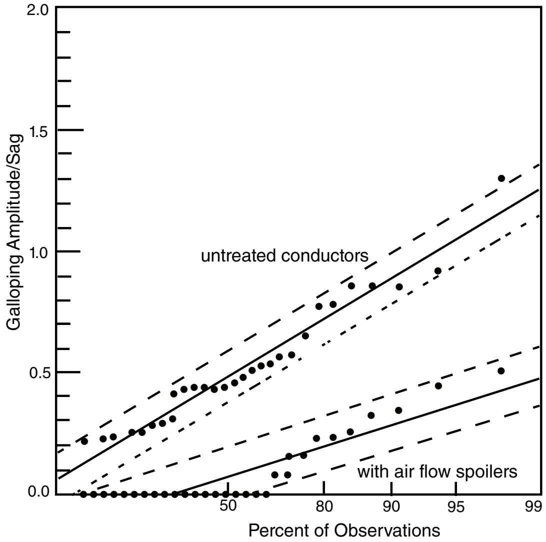


Figure 23: Reduction in peak to peak galloping amplitude due to installation of Air Flow Spoilers

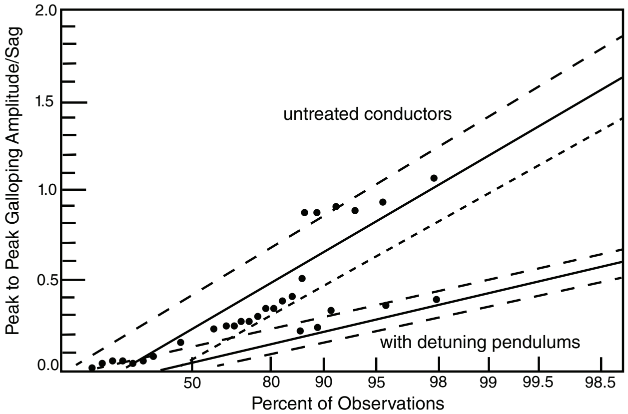


Figure 24: Reduction in peak to peak galloping amplitude due to installation of Detuning Pendulums

BENEFITS

- Demonstrated cost effective control of galloping.
- No moving parts therefore reliable, consistent maintenance free service
- Reduced power outages
- Allows upgrade of lines within the existing structure due to reduced need for clearances
- New lines can be more economically designed using smaller tower structures

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