CONDUCTOR GALLOPING

TUTORIAL PRESENTED AT THE

B2 MEETING

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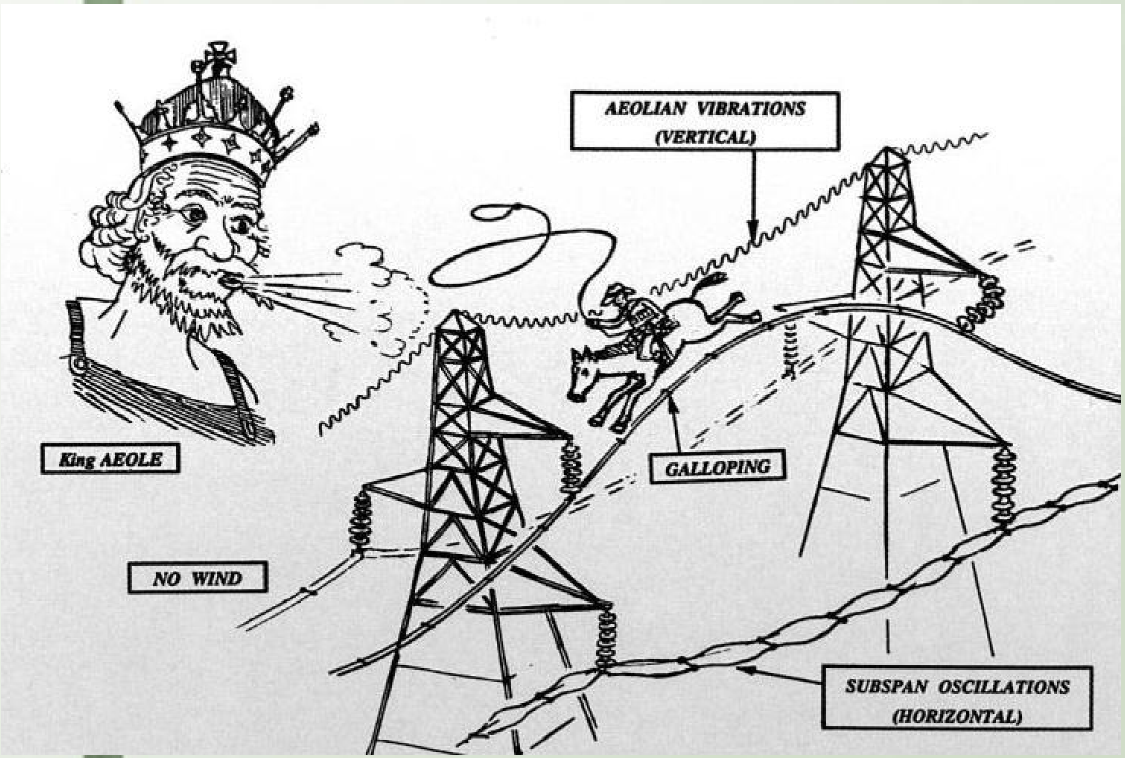
CIGRÉ B2 WG11
TASK FORCE ON GALLOPING

What is ice galloping? Definition



Galloping is a motion with:
- Low-frequency (from 0.1 to 1 Hz)
- Large-amplitude (from ± 0.1 to < ± 1 times the *sag of the span*)
- **U**p to 4 times the sag on distribution lines
- Wind-induced vibration of both *single* and *bundle* conductors

- **A** single or a few loops of standing waves per *span*
- **I**ce or wet snow accretion on the conductors
- It is a self-excited phenomenon.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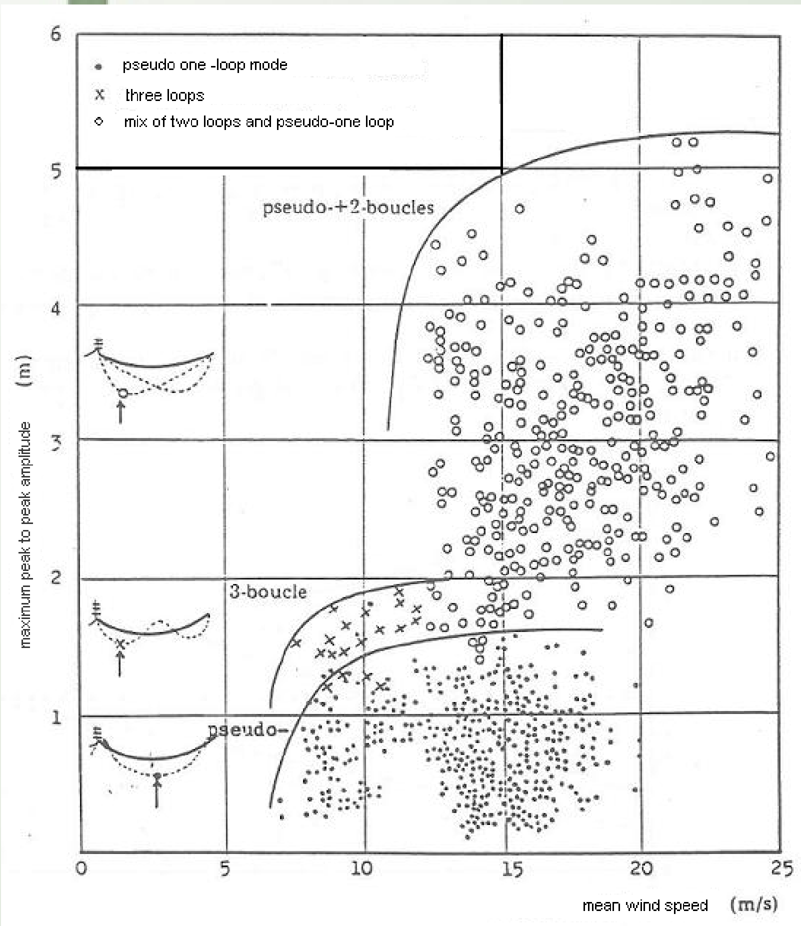
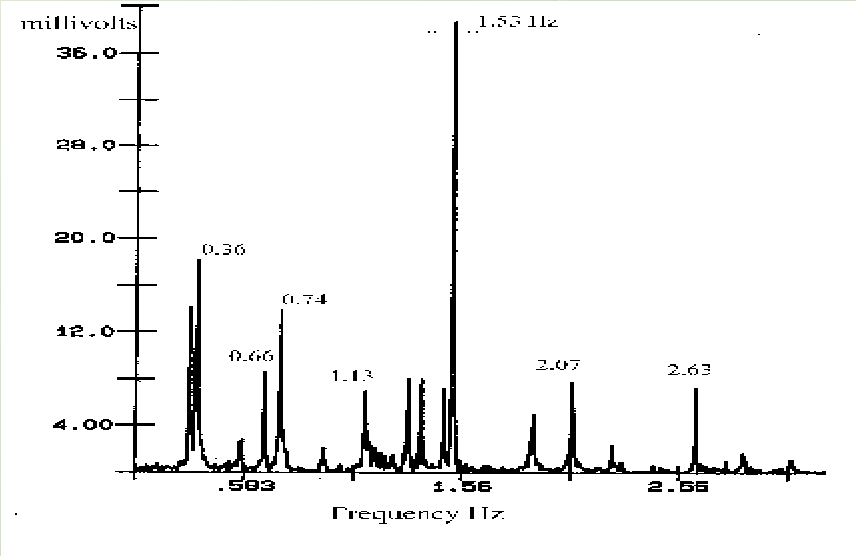
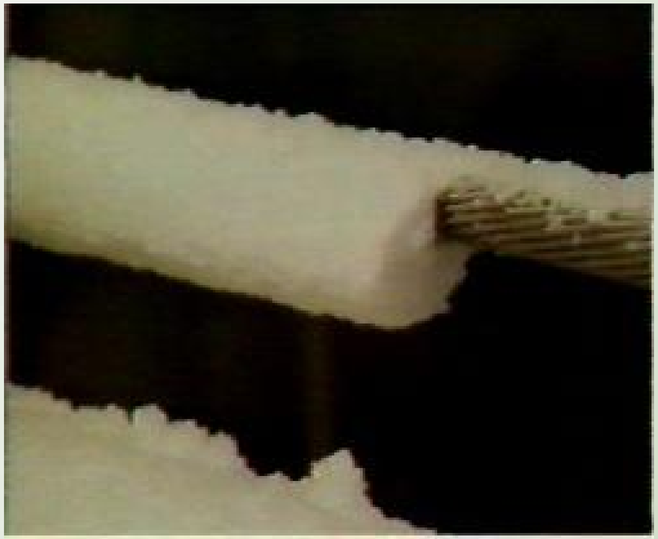
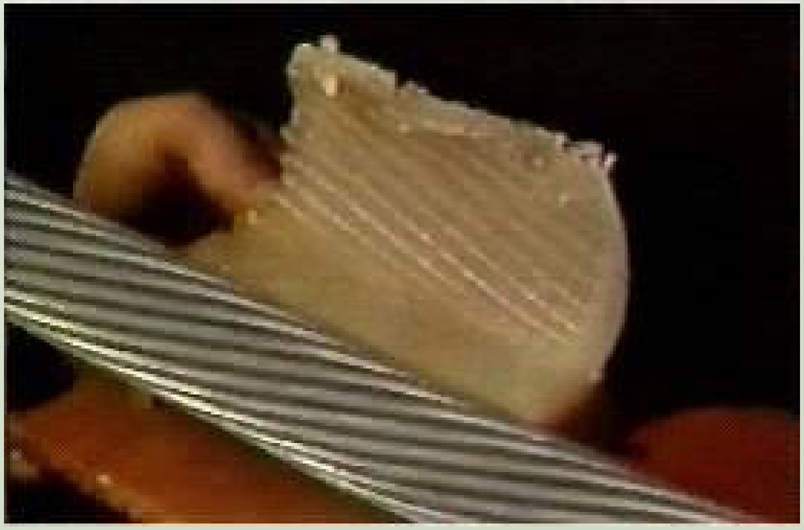
What is galloping ? : amplitudes





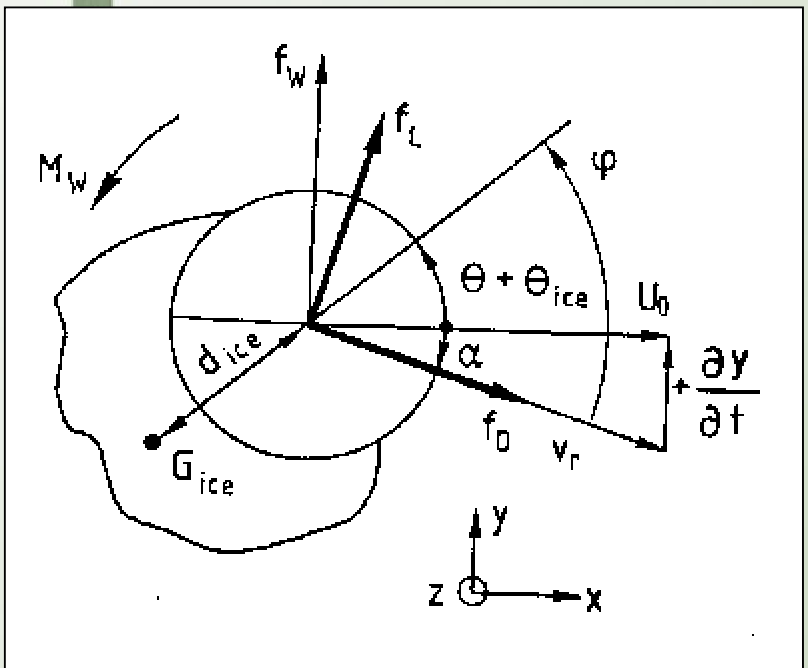
Left : Maximum observed amplitude versus wind speed at Kasatori-Yama test line
Above: Frequency spectrum of galloping motions
(Anjo et al 1974)

Bundle of 4x410 mm2 ACSR, two span section 312 and 319m, m = 6.7 kg/m, subconductor diameter 26 mm, tension 123000 N/phase, sag at 0°C = 6.5 m

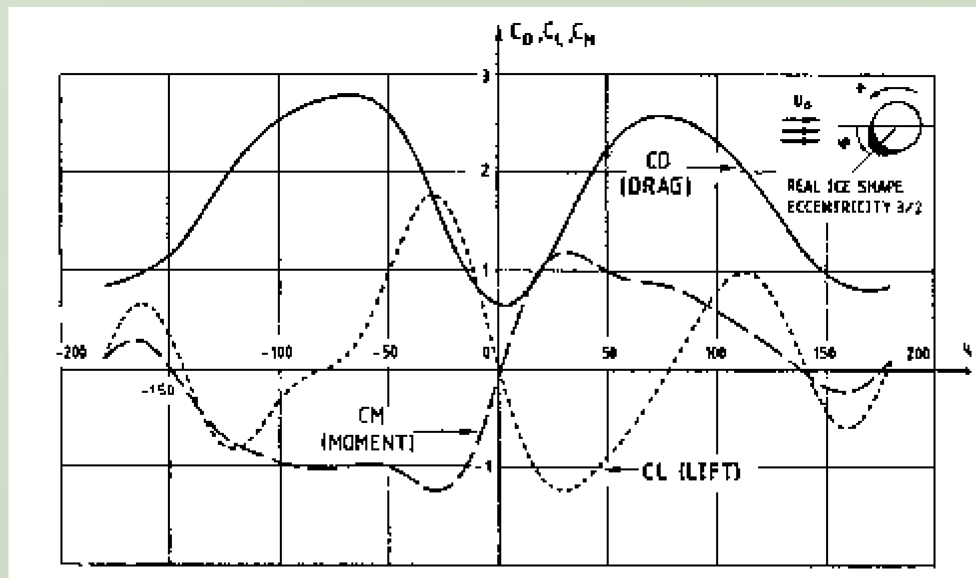
 

- Very thin ice shapes may induce galloping, particularly on single conductor lines
- Thicker ice shapes may also induce galloping, particularly on bundle conductor lines
- Ice density can be heavy, (glaze) or light (wet snow or rime)

What is galloping : aerodynamics



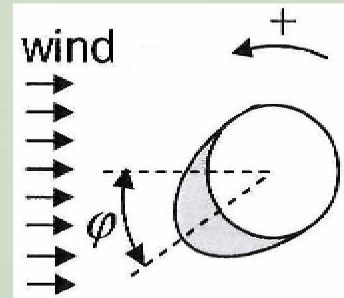
$$f_w = f_L \cos a + f_D \sin a$$



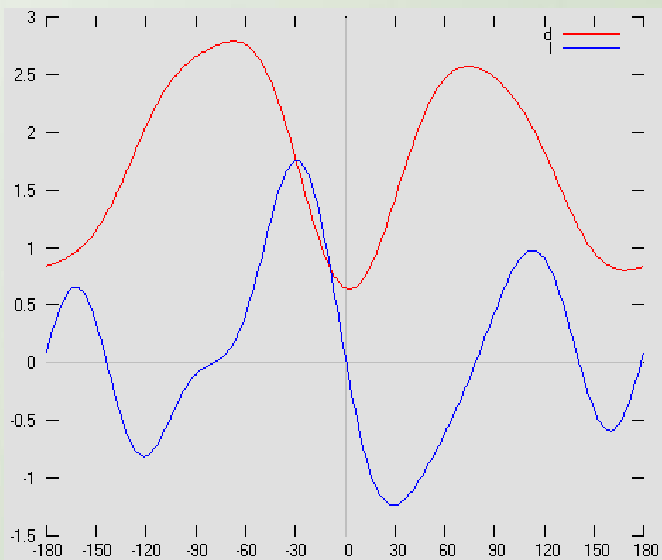
$$j = J_{ice} + J - a$$

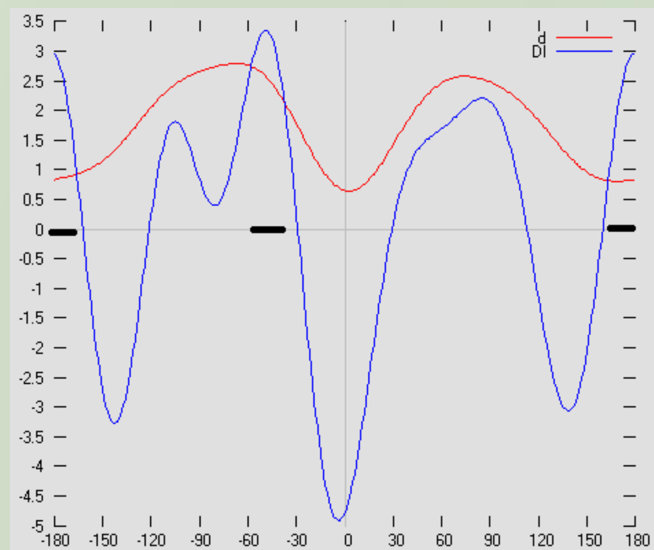
Den Hartog Mechanism

- **Only aerodynamic forces are important**
- Torsion is either negligible or forced by vertical movement
- Torsional frequency and damping not important
- Probably rare, except for reverse wind



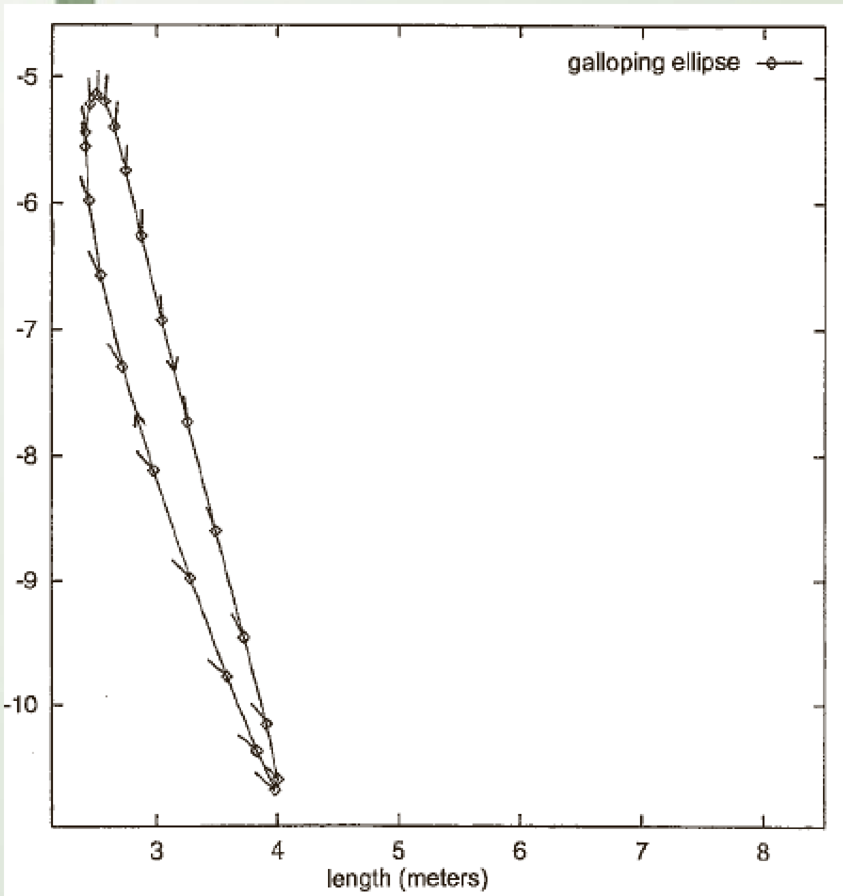
$$C_D - C_{La} < 0$$





Flutter Mechanism

$$(C_D - C_{La})\frac{w\, y_{\max}}{V} < C_{La}.J_{\max}.\sin f$$



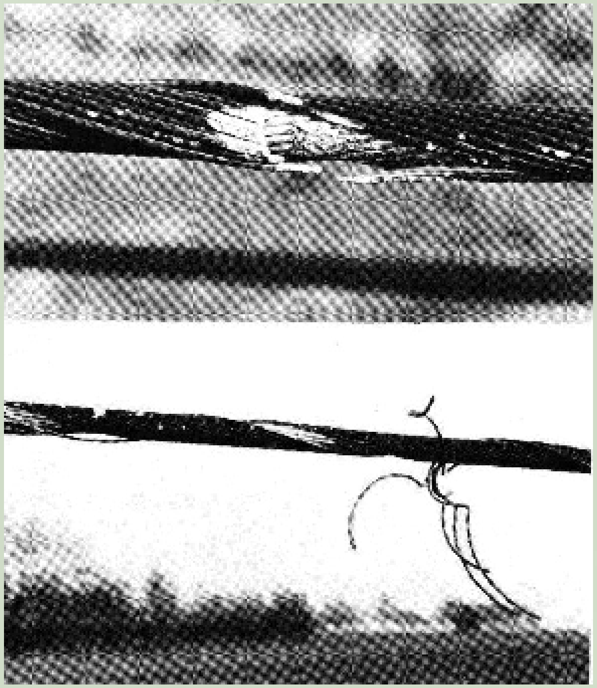
- Coupling between vertical and torsional movement is central to the mechanism
- Torsion is essential for energy transfer to vertical movement
- Structural data <u>and</u> aerodynamics important
- Ratio vertical to torsional frequency important
- Control of torsion by damping or detuning is essential for control
- Probably the most common mechanism, particularly on bundle conductor lines

Damage due to Galloping (1 of 2)

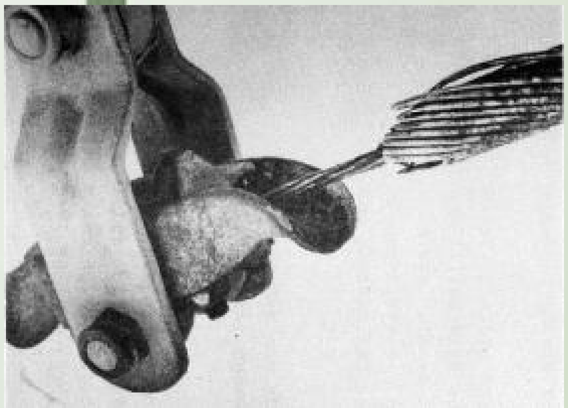
Many galloping events cause no damage

Modest galloping causes:-

- Flashovers between vertically aligned phases
- Circuit outages and
- Burns of conductors



Conductor burns due to galloping



Conductor fatigue damage due to galloping

Spacer damper broken due to galloping

Damage due to Galloping (2 of 2)

Insulator string broken during galloping

Tower member broken during galloping

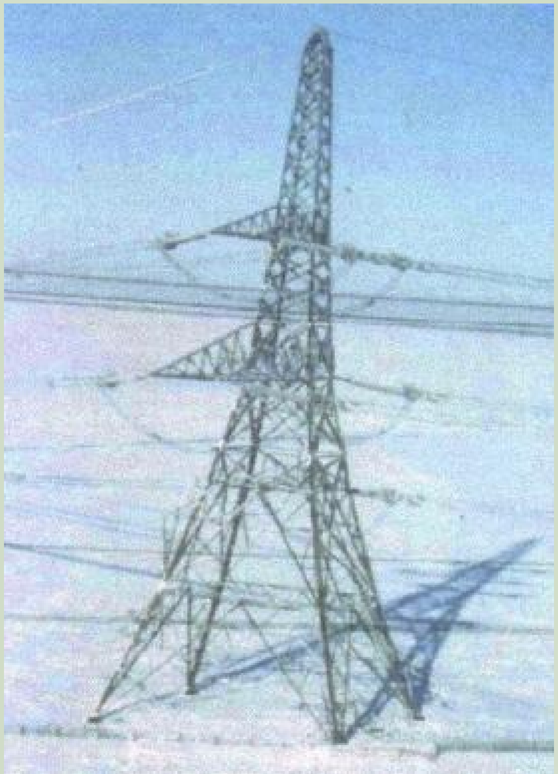
Severe galloping causes:-

- Loosened bolts
- Separated Insulator strings
- Broken hardware
- Fatigued conductor strands
- Fractured tower members
- Cascades of line sections

Dynamic galloping loads have been measured at:

Up to 2 x vertical load and
Up to 2.9 x horizontal tension

These need to be compared to fatigue, not tensile, strength



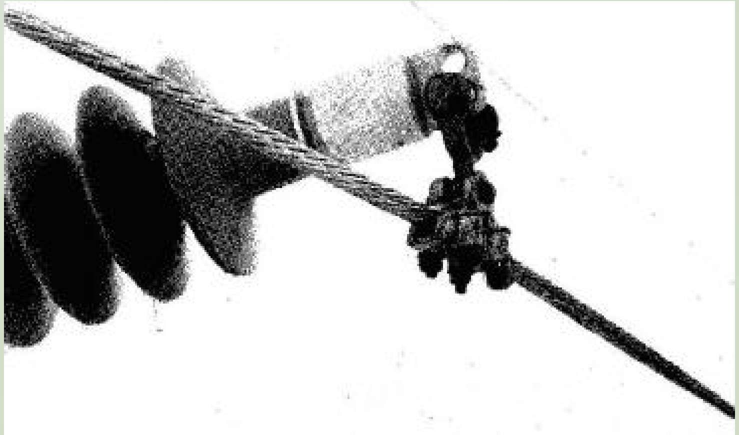
Tower with lower arm failed due to galloping

Control of Galloping (1 of 3)

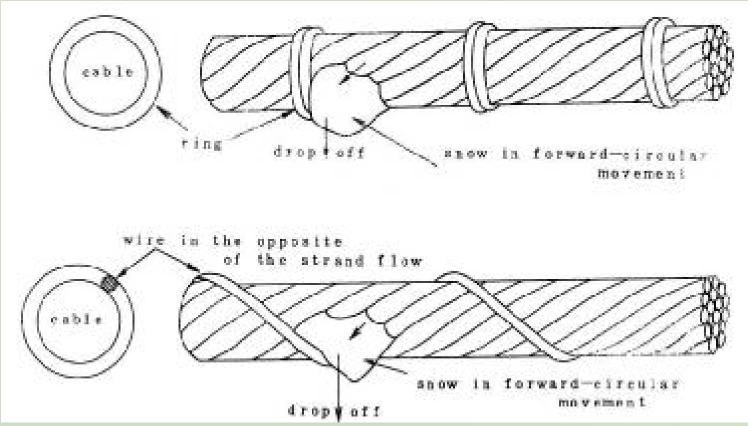
No device completely controls galloping

Clockwise from top right:

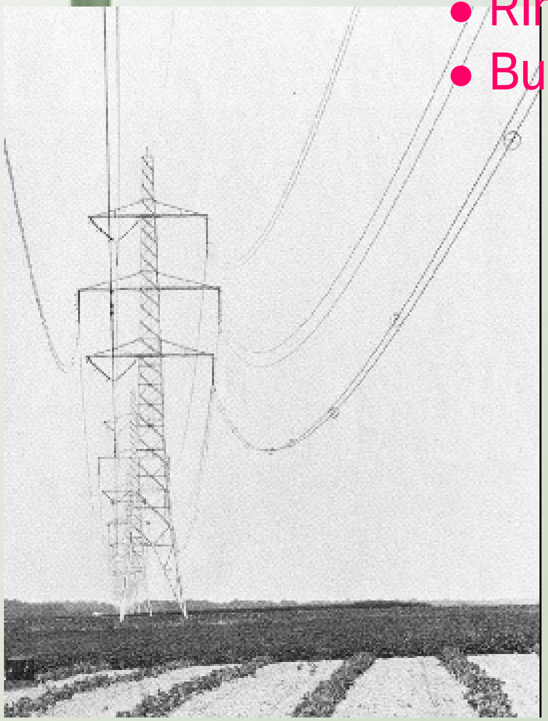
- Aerodynamically stable conductor
- Rings and spirals
- Bundle modification



Twisted pair conductor



Rings and spirals to remove wet snow

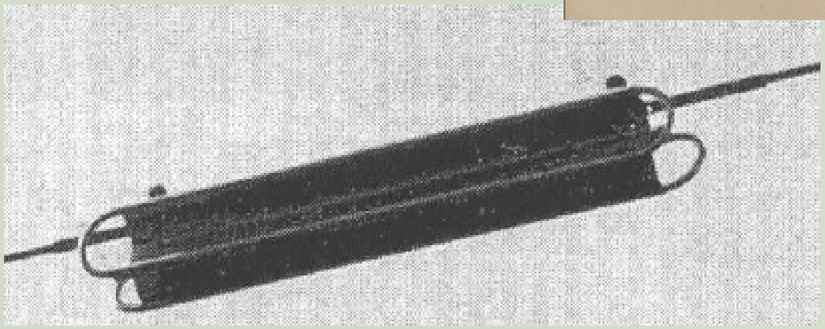


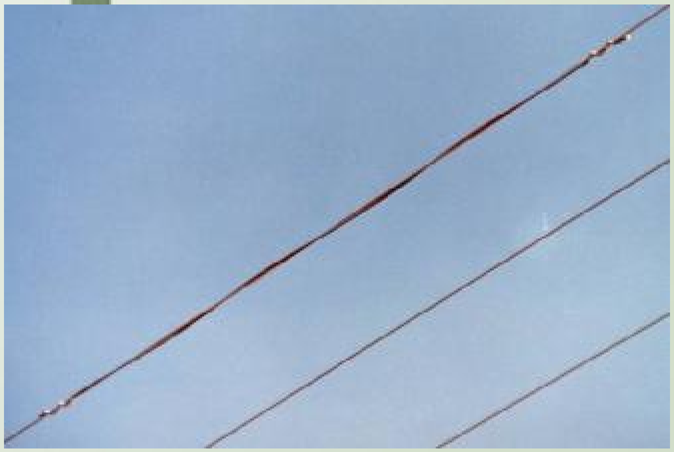
Vertically separated bundles with hoop spacers

Control of Galloping(2 of 3)

Clockwise from top left:

- Rigid Interphase spacers
- Flexible interphase spacer
- Aerodynamic drag damper
- Air flow spoiler

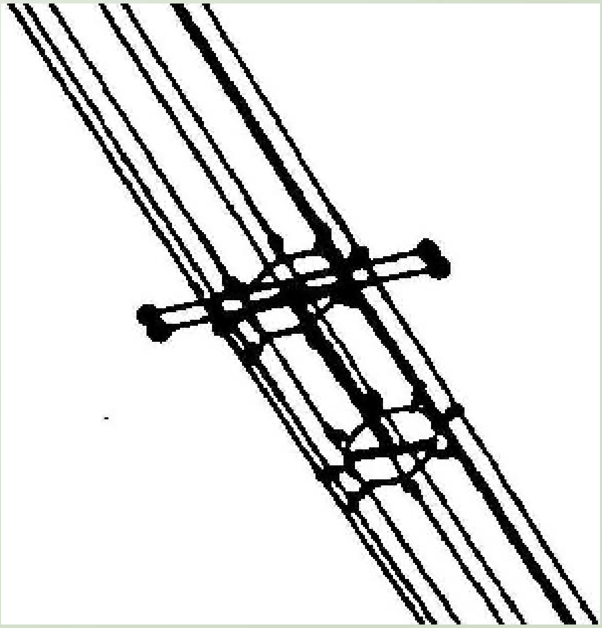




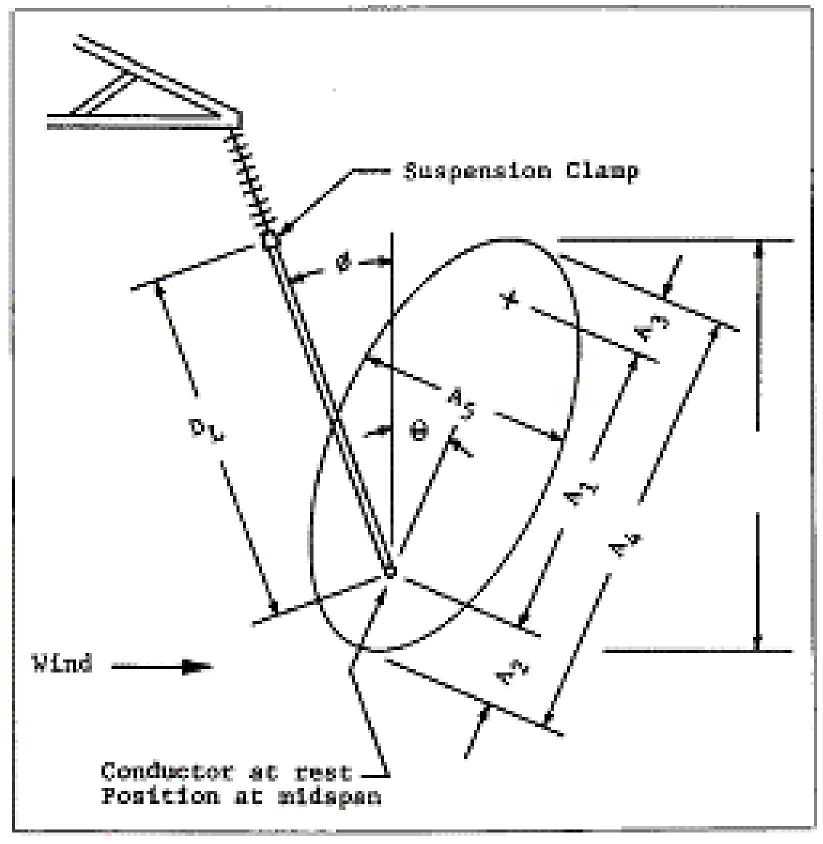
Control of Galloping (3 of 3)

Torsional devices clockwise from top right:

- Detuning pendulum for twin bundle
- Detuning pendulum for single conductors
- Torsional tuner and damper (GCD)
- Torsional damper and detuner (TDD)

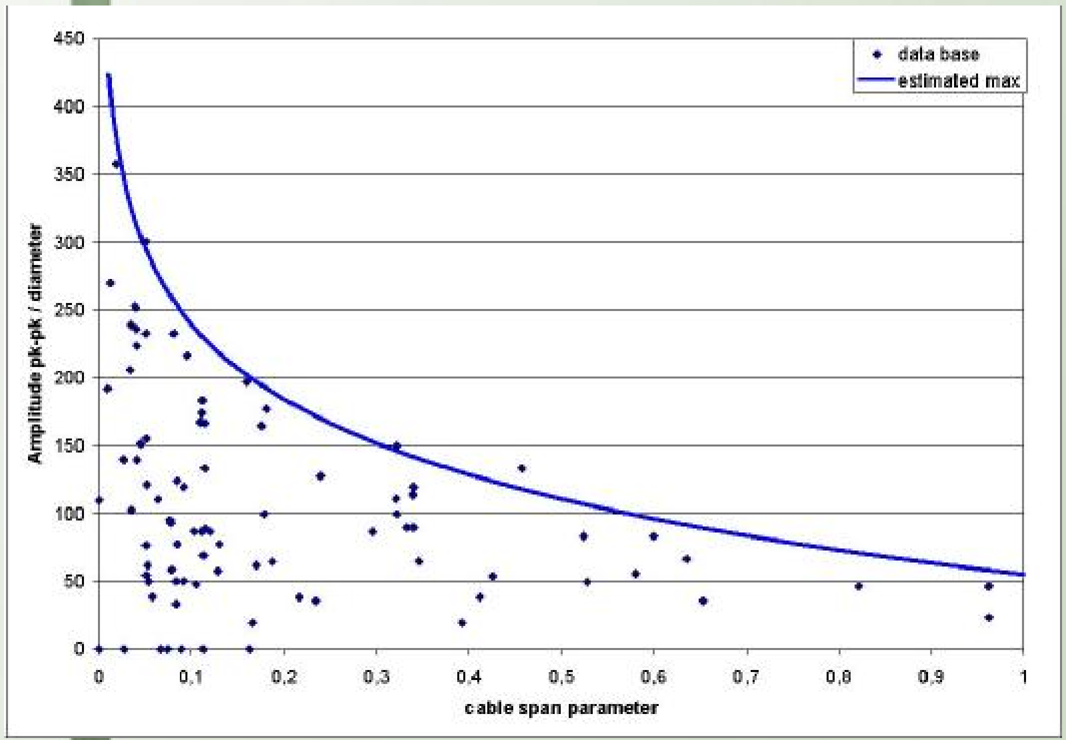


Design Against Galloping (1 of 2)



- *Common design method is elliptical clearance envelope - based on 1930s technology*
- *Vertical height based on multiple loop galloping on long spans*
- *Assumes limited motions on short spans*
- *Field data on galloping show deficiencies in assumed galloping motions*
- *Difference between galloping due to glaze ice and wet snow needs to be recognized*
- *Dynamic loads due to galloping are not explicitly included*
- *Design approach needs updating based on present knowledge*

Design Against Galloping (2 of 2)



Cable span parameter = 100 x diam / 8 x sag
Fitted curve: A/d = 80 ln (8 x sag / 50 x diam)

- Field data on galloping due to freezing rain are sufficient to define maximum amplitudes of motion on **single and bundle conductor lines.**
- Single conductor data shown, similar trend for bundle conductors
- More data are needed for galloping due to wet snow
- CIGRE could develop an improved design procedure.

Conclusions (1 of 2)

- Galloping on power lines may induce serious damage on all parts
- Occurrences are difficult to predict because they depend on the ice shape and density, wind speed and direction, and dynamic structural properties, such as natural frequency and stiffness of the conductor under the ice and wind conditions
- Galloping is a complex aeroelastic instability

Conclusions (2 of 2)

- Controls for preventing galloping are making progress
- The two mechanisms of galloping need different means of prevention
- Different ice and wet snow conditions need different treatment
- Single and bundle conductors need different treatment
- Design ellipses can be used for clearances and tower can be designed to resist these exceptional events
- New information is available to update design clearances for some conditions