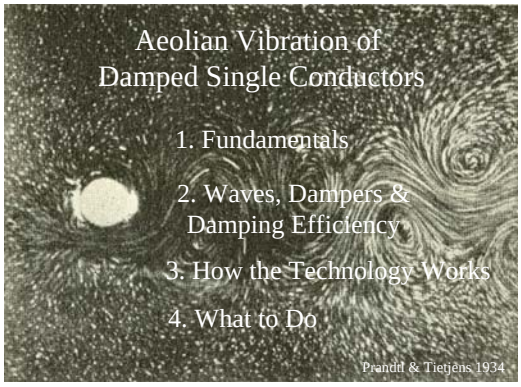
Aeolian Vibration

Chuck Rawlins

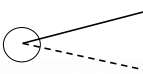
- Single conductors with dampers
- Bundled conductors
- Ground wires
- Insulators
- Davit arms
- Aircraft warning devices
- Etc., etc., etc.

1

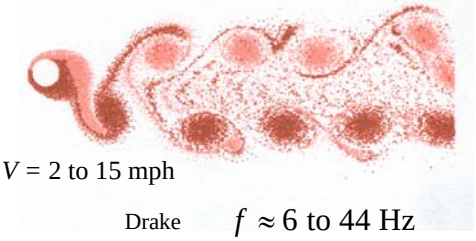


2

1. Fundamentals



$$f = St \cdot \frac{V}{D} \quad (St \approx 0.2) \qquad f\,(\text{Hz}) = 3.26 \cdot \frac{V\,(\text{mph})}{D\,(\text{inches})}$$

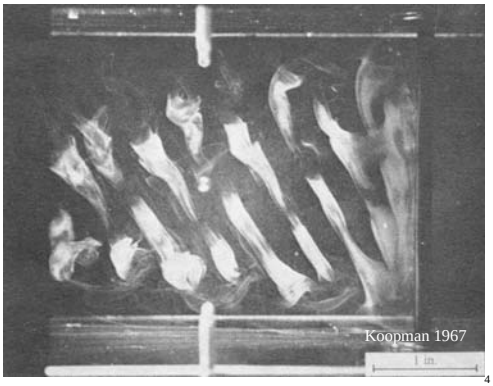


V = 2 to 15 mph

Drake $f \approx 6$ to 44 Hz

Fujarra et al (1998)

3



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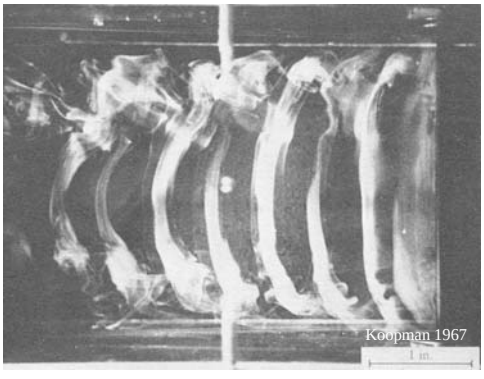
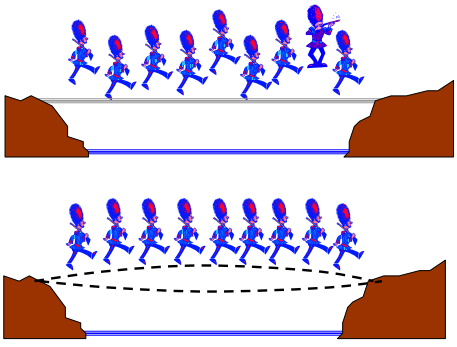


5

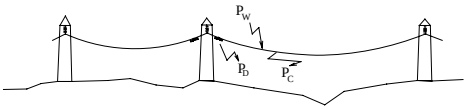
Fundamentals



6

Fundamentals

$$P_w - P_c - P_D = 0$$



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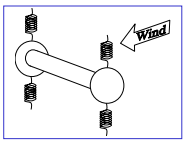
Fundamentals



Pick a wind velocity e. g. 10 mph.

Pick a conductor, e. g. Drake

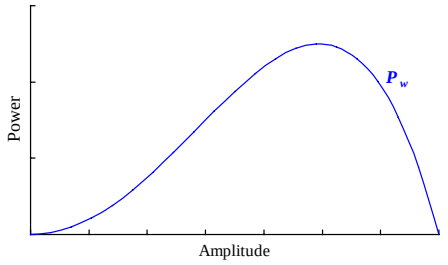
$$f = 3.26 \cdot \frac{10 \text{ mph}}{1.108 \text{ inches}} = 29.4 \text{ Hz}$$

8

Fundamentals

Power balance components

$V = 10$ mph

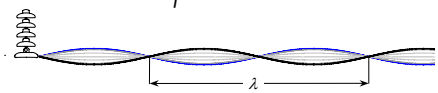


9

Fundamentals

Vibration loops

$$\lambda = \frac{1}{f} \cdot \sqrt{H / m}$$



Drake @ 25% RS

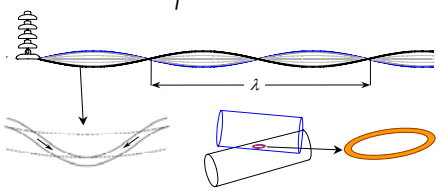
$\lambda \approx 11$ to 80 feet

10

Fundamentals

Self damping

$$\lambda = \frac{1}{f} \cdot \sqrt{H / m}$$

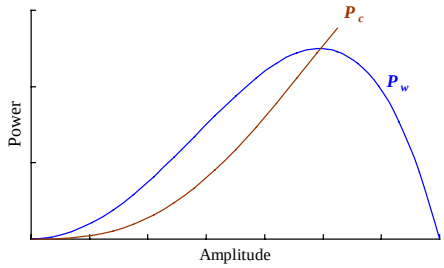


11

Fundamentals

Power balance components

$V = 10$ mph

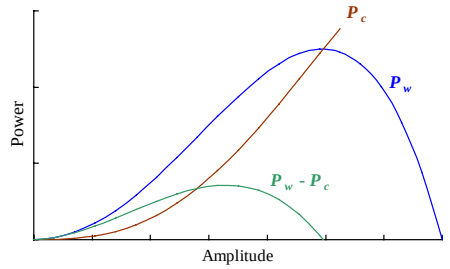


12

Fundamentals

Power balance components

$V = 10$ mph

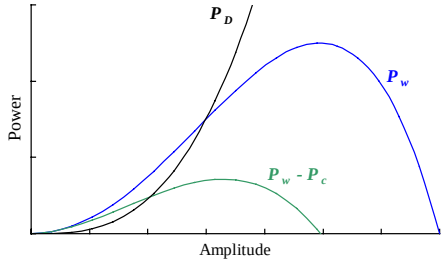


13

Fundamentals

Power balance

$V = 10$ mph

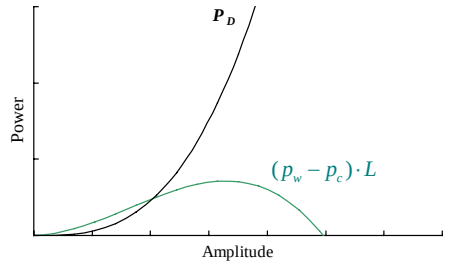


14

Fundamentals

Power balance

$V = 10$ mph

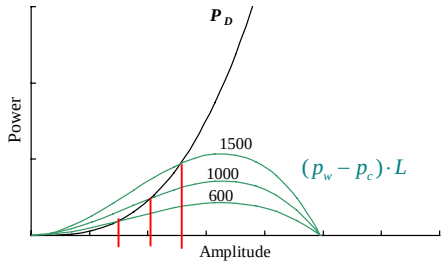


15

Fundamentals

Effect of span length

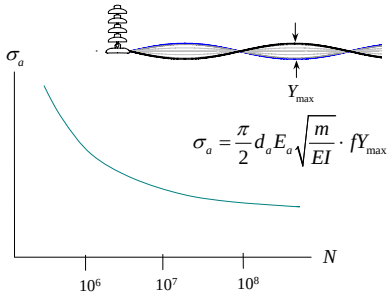
$V = 10$ mph



16

Fundamentals

Fatigue curve

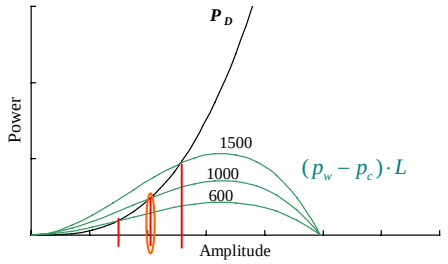


17

Fundamentals

Protectable span length

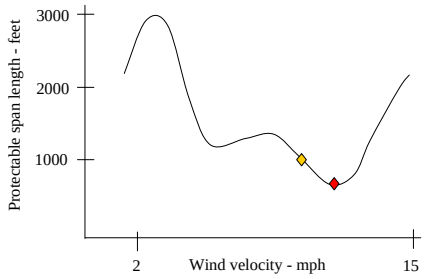
$V = 10$ mph



18

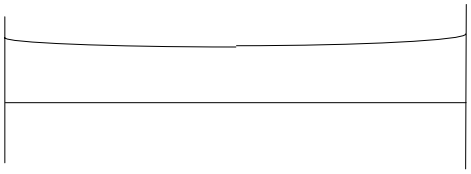
Fundamentals

Maximum safe span length



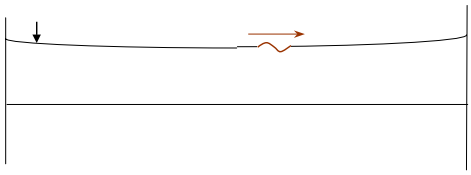
19

2. Waves, Dampers & Damping Efficiency



20

Waves & Dampers



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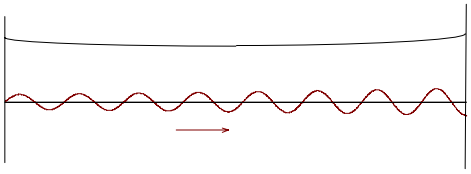
Waves & Dampers



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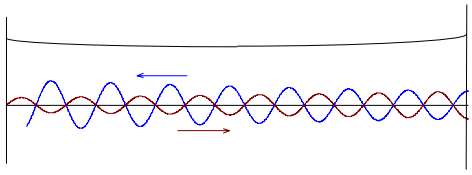
Waves & Dampers



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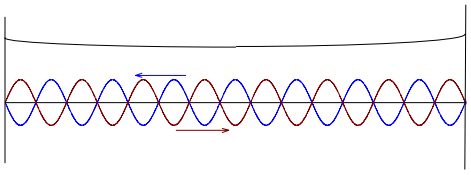

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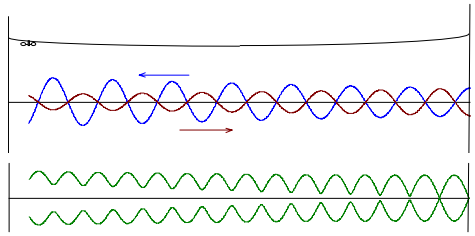
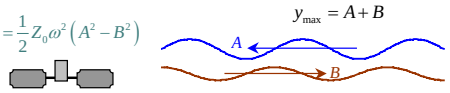


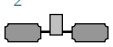
$$\omega = 2\pi f$$

$$P_A = \frac{1}{2} Z_0 \omega^2 A^2 \qquad P_B = \frac{1}{2} Z_0 \omega^2 B^2$$

$$P = \frac{1}{2} Z_0 \omega^2 \left(A^2 - B^2\right)$$

$$y_{max} = A + B$$

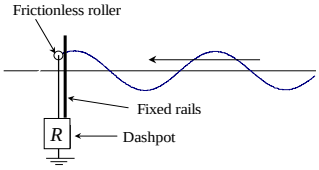




Frictionless roller

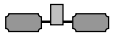
Characteristic Impedance

$$Z_0 = \sqrt{H \cdot m}$$



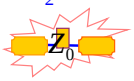
$$\text{Damping efficiency} = \frac{P}{P_{max}} = \frac{A - B}{A + B}$$

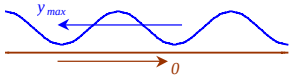
$$P = \frac{1}{2} Z_0 \omega^2 \left(A^2 - B^2\right)$$



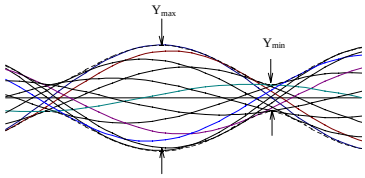
$$y_{max} = A + B$$

$$P_{max} = \frac{1}{2} Z_0 \omega^2 y_{max}^2$$

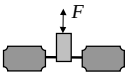


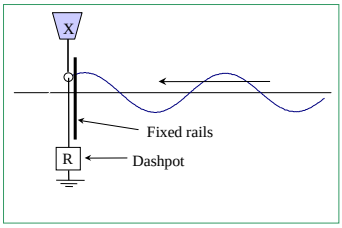


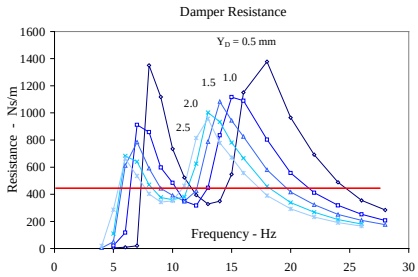
$$Y_{max} = 2(A + B) \qquad Y_{min} = 2(A - B)$$



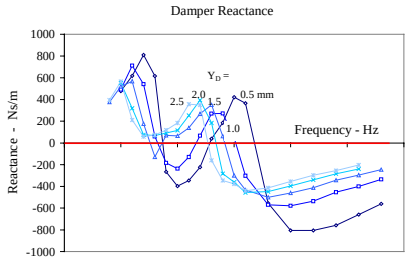
Damper resistance & reactance





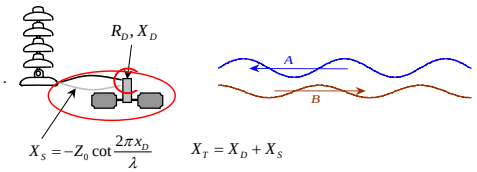


Waves & Dampers



31

Waves & Dampers



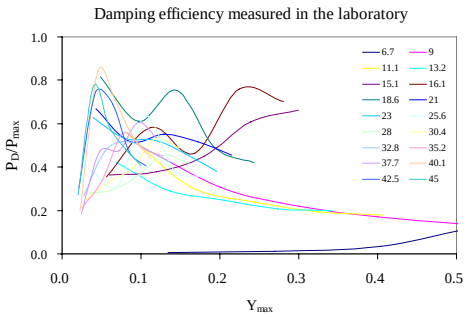
$$X_S = -Z_0 \cot\frac{2\pi x_D}{\lambda} \qquad X_T = X_D + X_S$$

$$\theta = R_D / Z_0 \qquad \chi = X_T / Z_0$$

$$\frac{P_D}{P_{max}} = \tanh\left[\frac{1}{2}\tanh^{-1}\left(\frac{2\theta}{1+\theta^2+\chi^2}\right)\right] \qquad \frac{Y_D}{Y_{max}} = \sqrt{\frac{P_D/P_{max}}{\theta}}$$

32

Waves & Dampers



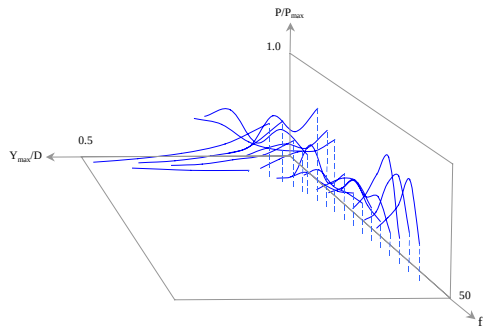
33

$$P_D = P_w - P_c$$

$$\frac{P_D}{P_{max}} = \frac{P_w}{P_{max}} - \frac{P_c}{P_{max}}$$

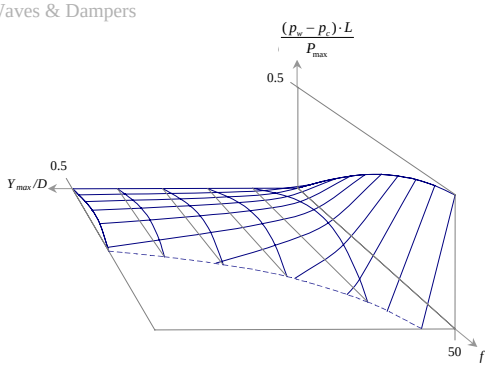
$$P_{max} = \frac{1}{2} Z_0 \omega^2 y_{max}^2$$

34



35

Waves & Dampers



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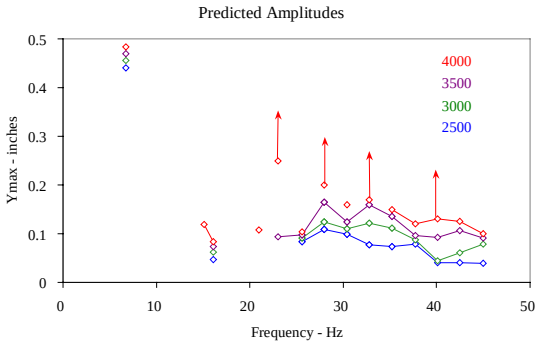

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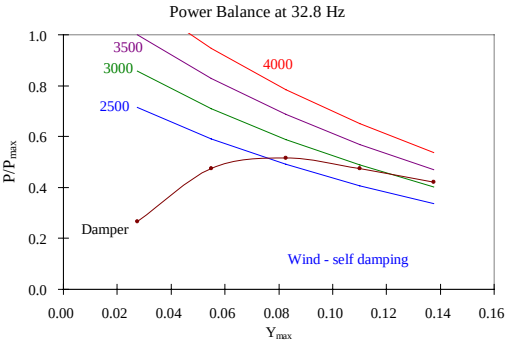

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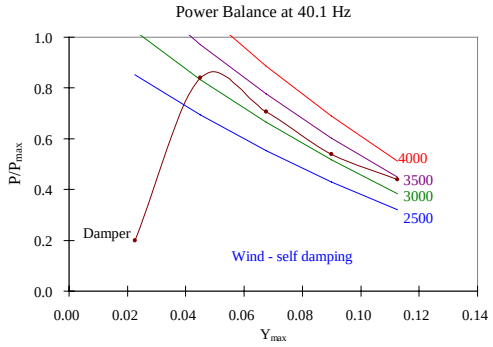


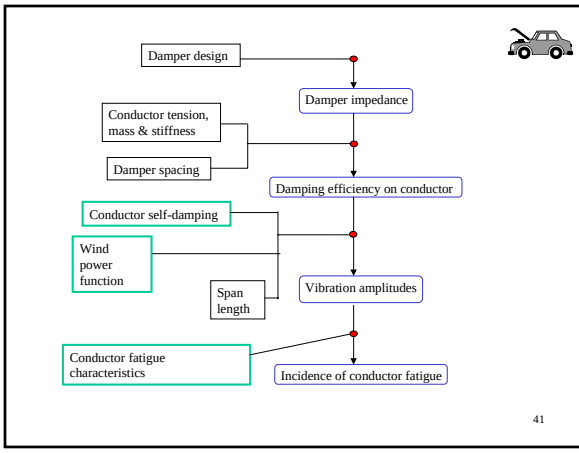
39

3. How the Technology Works

(a) A Look Under the Hood

(b) Road Test

40



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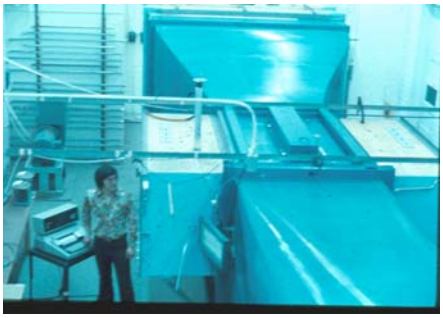
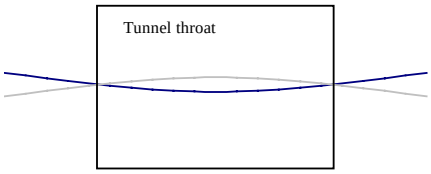


Courtesy Alcoa Laboratories

42



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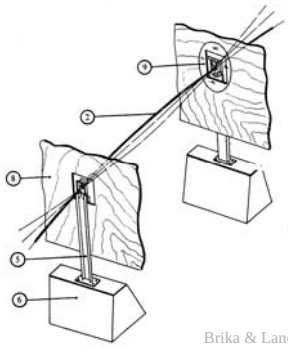
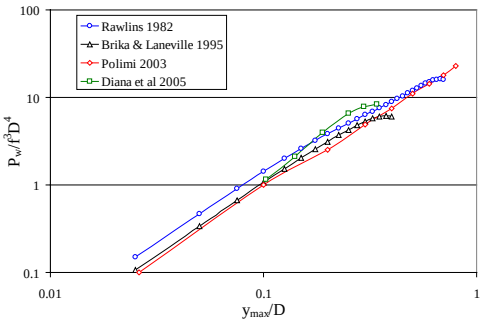


Brika & Laneville 1995

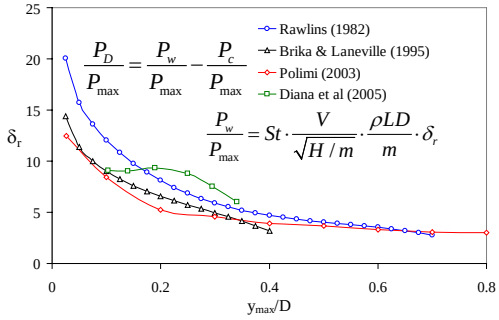
44

Specific Wind Power - Sine Loops



45

Reduced Decrement - Sine Loops



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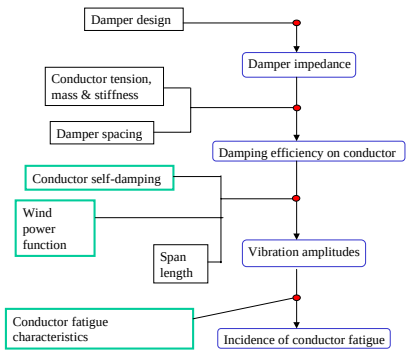


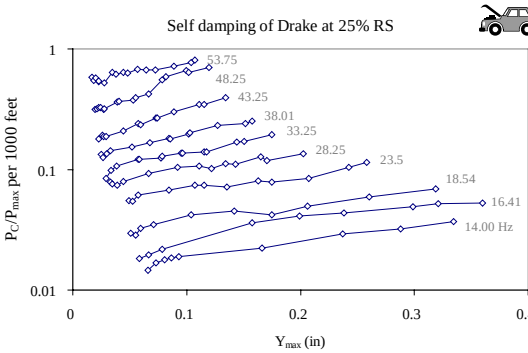
47

Measuring self-damping

Alcoa Massena

Memorial University of Newfoundland

48



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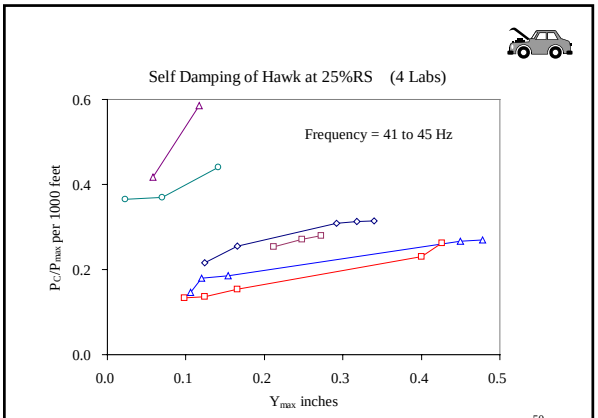

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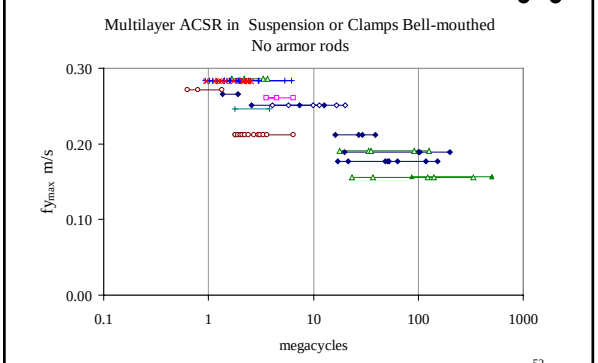
Courtesy GREMCA, University of Laval

51



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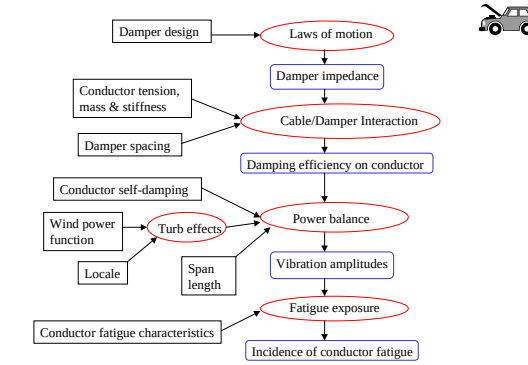

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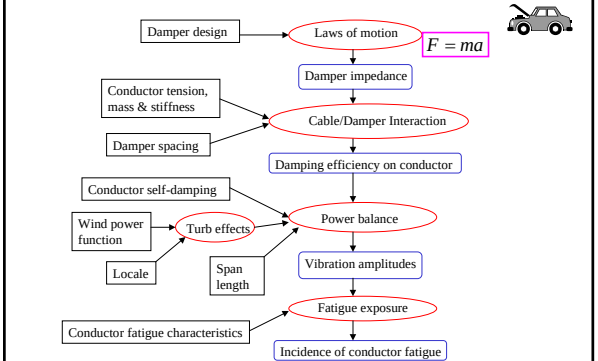

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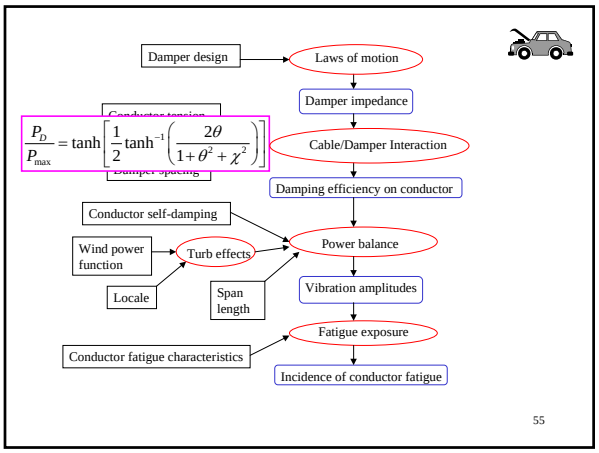
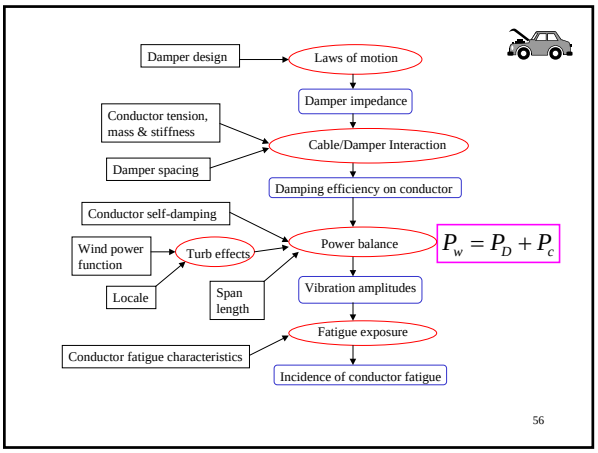
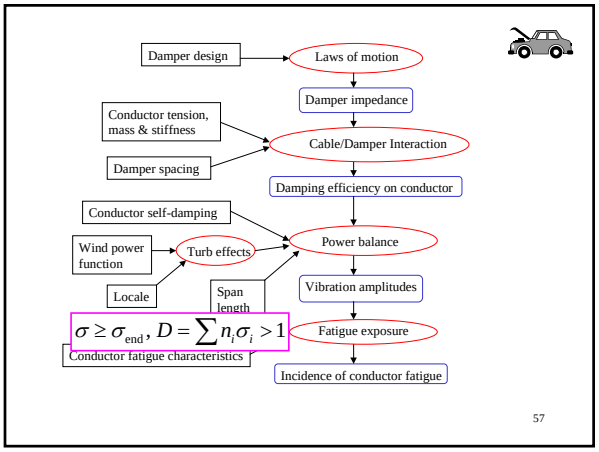
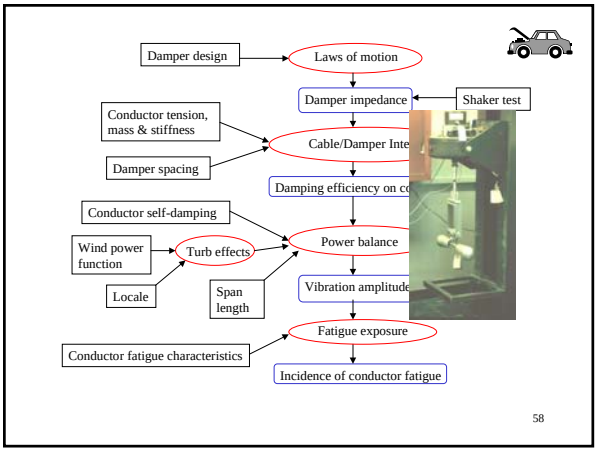
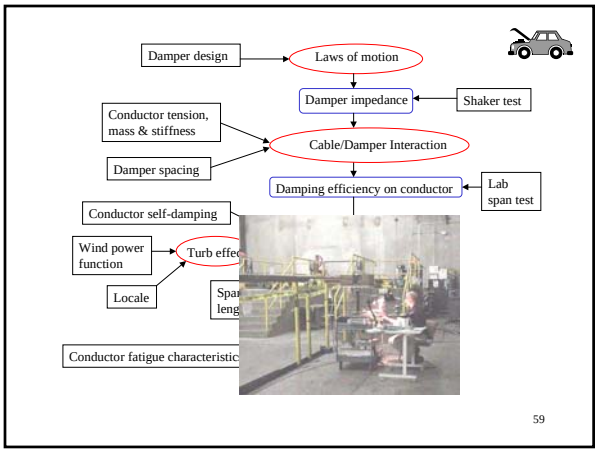
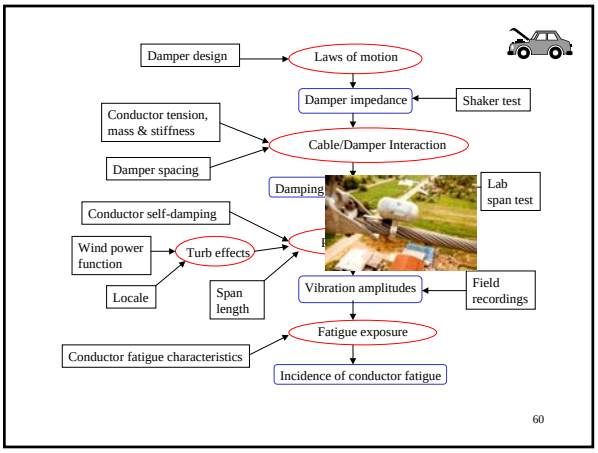

Damper design
Laws of motion
Damper impedance
$\frac{P_D}{P_{max}} = \tanh\left[\frac{1}{2}\tanh^{-1}\left(\frac{2\theta}{1+\theta^2+\chi^2}\right)\right]$
Cable/Damper Interaction
Damping efficiency on conductor
Conductor self-damping
Wind power function
Turb effects
Power balance
Locale
Span length
Vibration amplitudes
Fatigue exposure
Conductor fatigue characteristics
Incidence of conductor fatigue
55

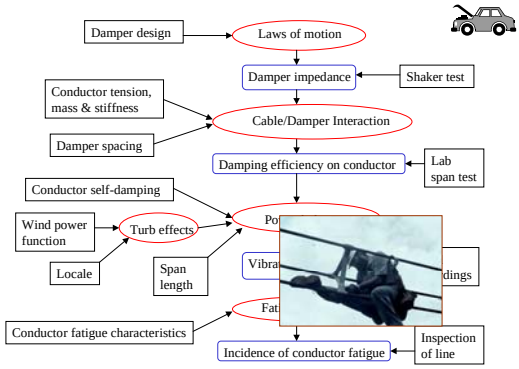

Damper design
Laws of motion
Damper impedance
Conductor tension, mass & stiffness
Cable/Damper Interaction
Damper spacing
Damping efficiency on conductor
Conductor self-damping
Wind power function
Turb effects
Power balance
$P_w = P_D + P_c$
Locale
Span length
Vibration amplitudes
Fatigue exposure
Conductor fatigue characteristics
Incidence of conductor fatigue
56


Damper design
Laws of motion
Damper impedance
Conductor tension, mass & stiffness
Cable/Damper Interaction
Damper spacing
Damping efficiency on conductor
Conductor self-damping
Wind power function
Turb effects
Power balance
Locale
Span length
Vibration amplitudes
$\sigma \geq \sigma_{end}, D = \sum n_i \sigma_i > 1$
Fatigue exposure
Conductor fatigue characteristics
Incidence of conductor fatigue
57


Damper design
Laws of motion
Damper impedance
Shaker test
Conductor tension, mass & stiffness
Cable/Damper Inte
Damper spacing
Damping efficiency on c
Conductor self-damping
Wind power function
Turb effects
Power balance
Locale
Span length
Vibration amplitude
Fatigue exposure
Conductor fatigue characteristics
Incidence of conductor fatigue
58


Damper design
Laws of motion
Damper impedance
Shaker test
Conductor tension, mass & stiffness
Cable/Damper Interaction
Damper spacing
Damping efficiency on conductor
Lab span test
Conductor self-damping
Wind power function
Turb effec
Locale
Span leng
Conductor fatigue characteristic
59


Damper design
Laws of motion
Damper impedance
Shaker test
Conductor tension, mass & stiffness
Cable/Damper Interaction
Damper spacing
Damping
Lab span test
Conductor self-damping
Wind power function
Turb effects
Locale
Span length
Vibration amplitudes
Field recordings
Fatigue exposure
Conductor fatigue characteristics
Incidence of conductor fatigue
60

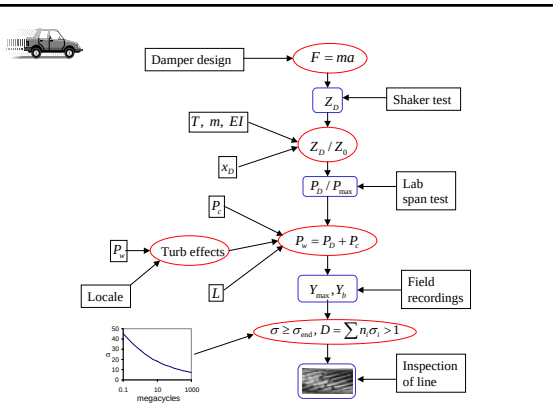


61

3. How the Technology Works

(b) Road Test!

62



63

The Source

CIGRE Study Committee B2 - Working Group 11
Task Force 1 "Vibration Principles" / G. Diana

Assessments of the Technology

"Modeling of Aeolian Vibrations of Single Conductors - Assessment of the Technology," *Electra No. 181* (1998)

"Modeling of Aeolian Vibrations of a Single Conductor Plus Damper: Assessment of Technology," *Electra No. 223* (2005)

64

IREQ's Varennes Test Line

The Course

Photo courtesy of IREQ

65

The Course

IREQ Varennes Test Line near Montreal

Conductor	Type	ACSR Bersfort (48/7)
	Diameter	35.6 mm
	Mass per unit length	2.37 kg/m
	Tension	36 kN
Span length	450 m (suspension)	
Type of terrain	open, flat, no obstruction, with snow cover (farmland)	
Position of the damper	one damper/span located 1.7 m from centre of the suspension clamp	

66

The Drivers

Diana et al (University of Milan)

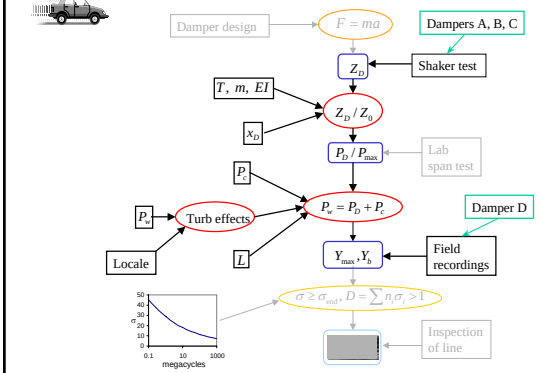
H-J Krispin (RIBE)

Leblond & Hardy (IREQ)

Rawlins (Alcoa Fujikura)

Sauter & Hagedorn (University of Darmstadt)

67



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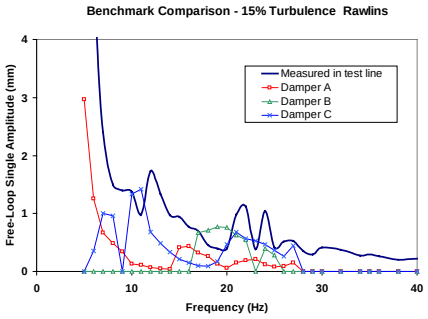
Results



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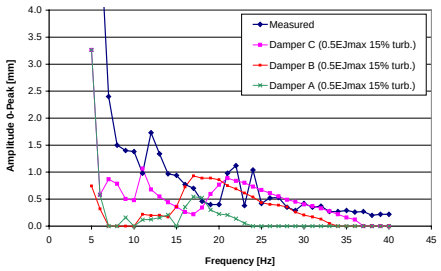
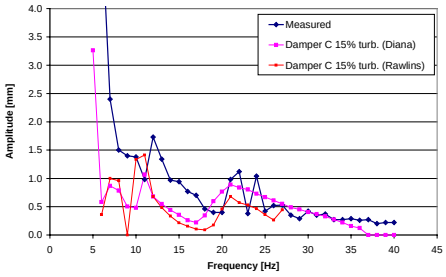
Results



Electra Fig. 15

70

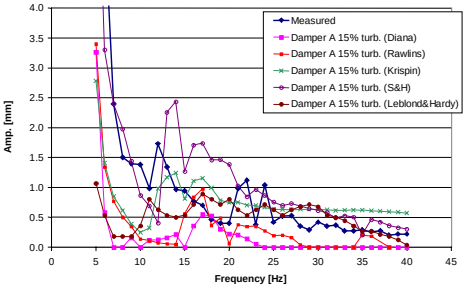
Results



Electra Fig. 17

71

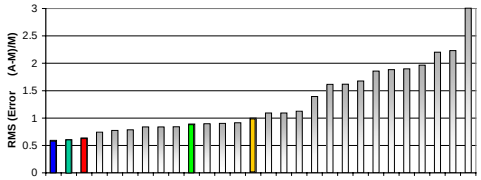
Results



Electra Fig. 18

72

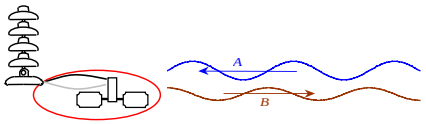
Best Runs



Electra Fig. 16

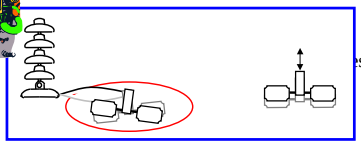
Differences between teams:

1. Wind power functions.
2. Self damping models.
3. Secondary effects, e.g. stiffness.
4. Modeling damper/conductor in different ways.



Differences between teams:

1. Wind power functions.



ess.

Differences with field data:

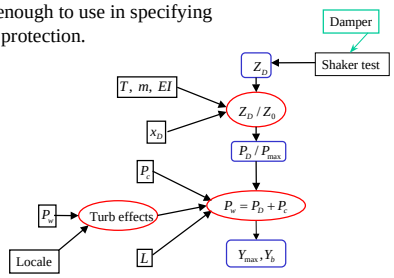
1. All of the above.
2. Modeling damper/conductor interaction.

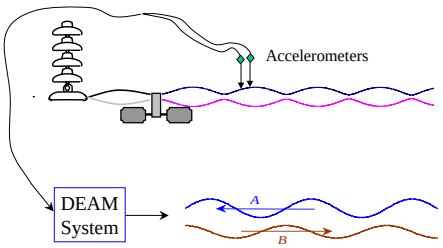
Benchmark Results

- The different teams differed widely in their predictions of vibration amplitudes.
- Some differences were due to different data bases on wind power and self-damping.
- None of the predictions agreed well with field measurements.
- This is mainly due to problems in the modeling of the interaction of the damper with the conductor.

Conclusion

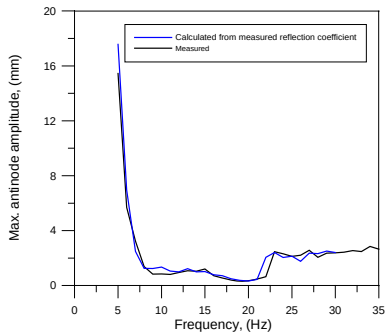
This branch of the technology is not accurate enough to use in specifying vibration protection.





$$P = \frac{1}{2} Z_0 \omega^2 \left(A^2 - B^2 \right)$$

Leblond & Hardy

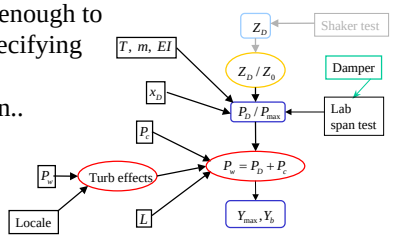


Leblond & Hardy

79

Conclusion

This branch may be accurate enough to use in specifying vibration protection..



80

1. Why did I spend all this time presenting the technology, when I knew it wasn't very useful to the designer?

2. OK, if that isn't useful, what is?

81

4. What to Do?

2. OK, if that isn't useful, what is?

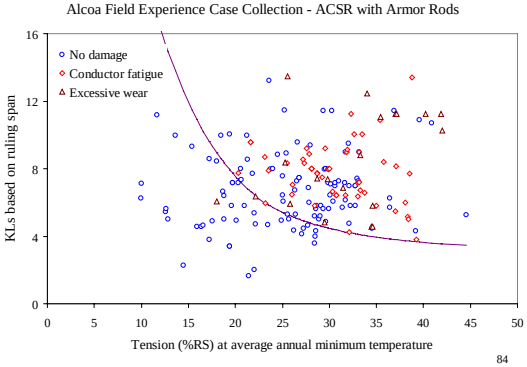
82

Resources:

1. Your own experience. If it worked before (or didn't), it will do the same again.

2. Experience of others. If it worked for them...

83



84

$$\frac{P_w}{P_{\max}} = St \cdot \frac{V}{\sqrt{H/m}} \cdot \frac{\rho LD}{m} \cdot \delta_r$$

$$\frac{P_w}{P_{\max}} = St \cdot V \cdot \rho \cdot \frac{LD}{\sqrt{H \cdot m}} \cdot \delta_r$$

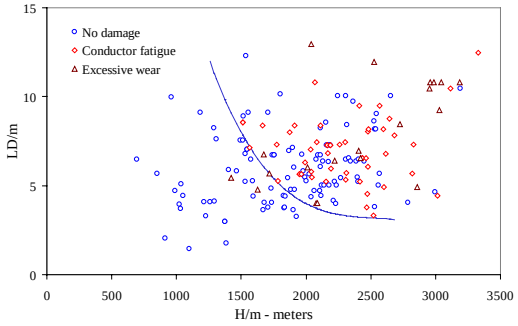
$$T_{\%} = 100 \cdot \frac{H}{RS}$$

$$K = \frac{D}{\sqrt{RS \cdot w}}$$

"Conductor Vibration - A Study of Field Experience," C. B. Rawlins, K. R. Greathouse & R. E. Larson, AIEE Conférence Paper CP-61-1090.

85

Alcoa Field Experience Case Collection - ACSR with Armor Rods



86

Safe Design Tension with Respect to Aeolian Vibrations
CIGRE B2 WG11 TF4 - Claude Hardy, Convenor

Part 1: Single Unprotected Conductors
Electra No. 186, October 1999

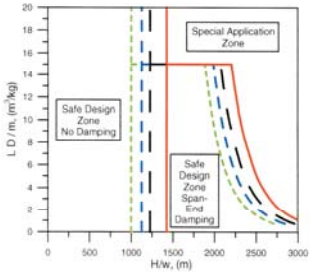
Part 2: Damped Single Conductors
Electra No. 198, October 2001

Part 3: Bundled Conductors
Electra No. 220, June 2005

Overhead Conductor Safe Design Tension
with Respect to Aeolian Vibrations,
CIGRE Technical Brochure No. 273, June 2005

87

Recommended Safe Tensions for Single Conductor Lines



CIGRE Brochure 273, Fig. 5.4

88

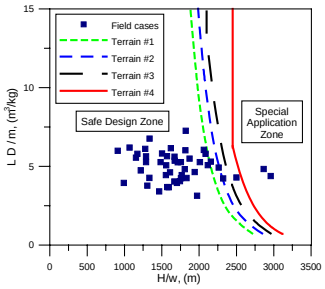


Figure 4 : Ranking parameters of twin horizontal bundled lines in North America fitted with non-damping spacers and end-span Stockbridge dampers in relation to estimated safe boundaries.

Electra No. 220, June 2005

89

Resources:

1. Your own experience. If it worked before (or didn't), it will do the same again.

2. Experience of others. If it worked for them...

3. Your friendly….

90

Damper Suppliers!

WHAT??

91

Why???!!

All suppliers have some system for making recommendations.

They have the most comprehensive knowledge of their system's performance.

They are well motivated to avoid repetition of any unsatisfactory performance.

They are in the best position to maintain the system to achieve that.

92

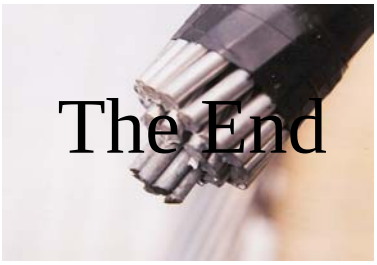
Protection recommendations will not agree.

1. Suppliers have different technical approaches.

2. Their damper designs are different.
3. Their exposures to field experience have differed.

1. Why did I spend all that time presenting the technology, when I knew it wasn't very useful?

93



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