V I B R A T I O N S

1 Theory

Vibration appears at moderate windspeed, approximately 2-6 metres/second and the mast theoretically oscillates in a direction perpendicular to the wind. In practice nearly all vibration occurs in an athwartships wind direction.
The oscillations are caused by alternate eddy shedding on the lee side of the mast and the frequency depends on wind speed, mast section sizes and, to a minor extent, shape.
Despite its great technical importance, the ”Karman” effect still contains many uncertain details, not only for yacht masts, but also for chimneys and similar constructions.
When the natural frequency of the mast coincides with the frequency of eddy shedding, resonance is said to occur.
The vibrations become noticeable when the wind speed is approximately 80 % of the resonance wind speed. They increase as wind speed increases (the wind ”takes” the vibrating mast as being bigger than it really is). The vibrations thereafter decrease as wind speed increases to approximately 1,5 times the resonance
wind speed.

2 Factors which affect the amplitude

The amplitude greatly depends on the longitudinal dimension of the mast, but weight per meter and external mechanical damping (theoretically aerodynamic damping as well) affect the amplitude.
By making the mast thin longitudinally the amplitude decreases. If weight per meter is increased amplitude decreases as well. An increased weight will automatically be the consequence of decreased dimensions if inertias are kept because of strength requirements. A mast with small amplitude will be heavier and consequently more expensive.
Increased damping (only the mechanical damping is of any importance) will decrease the amplitude but is hard to accomplish. We are continuously working on this but have not, up till now, found any suitable solutions.
One type of damping is to stay the middle part of the mast fore and aft with a relatively stiff wire (ordinary rope completely lacks staying effect) see 3.
A completely different way to decrease the amplitude is to disturb the eddy detach.
The sail strip recommended by us works after this principle. The flexible strip gives a random vortex detach on the lee side of the mast and resonance is prevented.
The principle with vortex disturbing spirals (”scruton”-spirals which are mounted on the upper part of some chimneys) can also be used for masts.
Spiral strips are mounted on the middle fifth of the mast. To obtain maximal effect spirals should project 0.1 x D (D = longitudinal dimension of mast from the mast surface. The pitch should be approximately 5 x D and the vertical measure between two neighbouring strips should be 1.7 x D.

3 Factors that affect the resonance wind speed

When taking measures that change the resonance wind speed the resonance will return at another wind speed. The problem area will only be moved.
Sometimes, however, it might be useful to change the resonance wind speed. For a given mast the natural frequency can, for example, be changed by staying the middle part of the mast or by increasing mast compression.
A staying of the middle part of the mast can give a considerable increase of the natural frequency of the mast and consequently an increase of resonance wind speed. To be effective the staying must consist of stiff wires, fore and aft, and staying angles between stays and mast must not be less than 20°.
Increased mast compression (accomplished by tensioning the fore/back stay(s) decreases the natural frequency and consequently the resonance wind speed. If the fore/backstay tension is increased by 50% the resonance wind speed decreases by 15%. The effect is marginal.

4 Literature

For further studies of these matters the following literature is recommended:

Sachs, Peter	Wind forces in engineering
Rosemeier	Winddruckprobleme bei Bauwerken

These books also contain further references for deeper studies.