Limits of Vibration Damper Performance

Introduction

Whenever one hears a humming sound near an overhead power conductor it could be the audible noise of the AC current passing through the conductor to a residence, an industrial plant, or other destinations. That would be occurring at the rate of 60 cycles per second and is well within the audible range. On the other hand it could also be conductor vibration caused by relatively low winds, say in the range of 3mph to 20mph. Above 20mph the winds have too much turbulence to create this type of vibration. It is called aeolian vibration, or vortex vibration because it is caused by vortices moving off the conductor in the wake. The rate of vibration in this case varies according to the wind speed and the diameter of the conductor. Depending on the conductor diameter it could range from five to over 100 cycles per second.

Each vortex, as it moves downstream, applies an impulsive vertical force to the conductor as it leaves. The rate of this impulsive force, for a one inch diameter of conductor, varies from seven times per second to 72 times per second in the range of wind speed from 2mph to 20mph. During the time of one cycle a vortex has moved away from the conductor a distance of five diameters. Its influence on the conductor is greatly diminished as it moves away in the wake.

The forces acting vertically on the conductor are repetitive in nature, in a word, "sinusoidal". They repeat in up and down direction every cycle. Such forces would not be troublesome if the conductor were completely rigid. All conductors, unfortunately, as well as many other cables, steel and otherwise, are flexible, and will respond to repetitive forces by vibrating in certain mode shapes. These shapes are called natural modes and there are literally over one hundred such modes in a span length of 1,000 feet. The first twenty or so modes are not capable of causing trouble because the natural frequency is too low and the wave lengths are too long . The shape of these modes along the span length is also sinusoidal, and are called "standing waves". When the wind speed reaches 5-10mph the frequency of vortex-induced force is 18 to 36 cycles per second on the one inch conductor (on a two inch diameter it would be 9 to 18 cycles per second). For ***any diameter*** conductor there will be many natural frequencies and modes within the wind speed range given (5-10mph). Each of these natural frequencies could coincide with the given vortex shedding frequency, presenting a ***resonance between conductor vibration and vortex excitation.*** Unless there is a sufficient level of structural damping within the conductor itself, the resultant vibration will produce fatigue failure in the conductor strands over time. The same picture could be presented for steel guy cables on a TV tower, or back stay cable on a bridge , or hanger steel cables on a suspension bridge. The problems are the same.

Vibration dampers are used to add damping to the motion and reduce the amplitude of vibration below the fatigue danger level. The purpose of this note is to illustrate the methodology for assessing limits of performance for such dampers.

Types of Vibration Dampers

There are two types of vibration dampers in use today, the Stockbridge type and the Impact type. In the first it is given the name after G.W. Stockbridge the first inventor of the device in 1926. It consists of two weights suspended by a small steel stranded cable on either side of an aluminum clamp. The photo #1 illustrates this device attached to steel guy cables on a TV tower. There are four “Stockbridge dampers” per guy cable.

Photo #1 Stockbridge dampers attached to TV tower guy cables

The second type of damper is the Impact damper. Three types of devices are used on power conductors and steel guy cables. The first type, designated here as Ring Damper II is seen in accompanying Photo #2 below. See also the link to installation instructions at www.arproducts.org/installation.

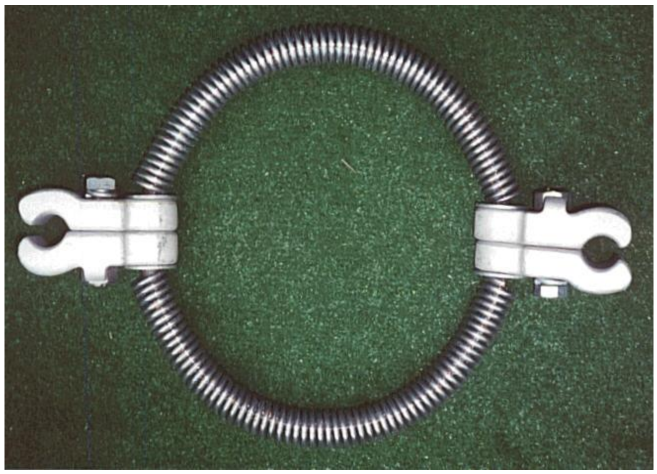


Photo #2 Ring Damper II - used on guy cables and power conductors

The damper consists of a steel hoop inside of two galvanized steel springs and two aluminum clamps used to attach the damper to the cable or to conductors. When it is used on guy cables it is attached with the ring tilted along the cable direction and the clamps rotated downwards to grasp the cable. A single galvanized bolt and ANCO lock-nut secures the clamps to the steel cable.

Vibration may occur in any direction around a 360 degree circle around the cable axis depending upon the orientation of the cable relative to the wind direction. In the case of the ring damper the vibration may be resolved into vector components parallel to and perpendicular to the plane containing the ring. That plane is green in the photo. Thus, the device must provide energy absorption in both planes at once during the vibration.

In order to verify that the ring damper will perform, when it is vibrated either in-plane or out-of-plane, tests were performed at National Electric Energy Testing Research & Applications Center (NEETRAC) in 1995. The center is a unit of Georgia Institute of Technology, near Atlanta, Georgia.

In the case of the Stockbridge type of damper it must also be able to dampen vibration in any direction. Since these dampers were developed primarily for electric power conductors they are designed to dampen vibration in the vertical plane only. In laboratory tests they are vibrated only in the vertical plane. No information is available for out-of-plane vibration of Stockbridge dampers.

There are standards for conducting laboratory tests of vibration dampers for use on power line conductors. This standard is available from the Institute of Electrical & Electronics Engineers (IEEE) under IEEE Standard no. 644. It provides guidelines for laboratory testing of vibration dampers by means of electro-dynamic vibrators. Nothing is called out in the standard to provide for vibration out of the vertical plane. Yet, such dampers are used on vertical steel hangers for suspension bridges, back-stay cables on bridges, as well as their use on guyed tall towers, seen in Photo #1.

Comparison of Performance

It is of interest to compare the damping performance of the two damper types introduced above. Tests were also performed on a model 1709 ALCOA device at the same time the Ring damper was tested. Two other types of impact damper were also tested at NEETRAC. These comparison results are shown in the appendix.

ANALYSIS

A comparison of the damper tests in the appendix reveals the following:

- The ALCOA damper has a sharp spike and a narrow band feature
- The AR DAMPER devices have a broad band characteristic
- The ALCOA damper is more effective at low frequency (low wind)
- The AR DAMPER is more effective at high frequency (high wind)

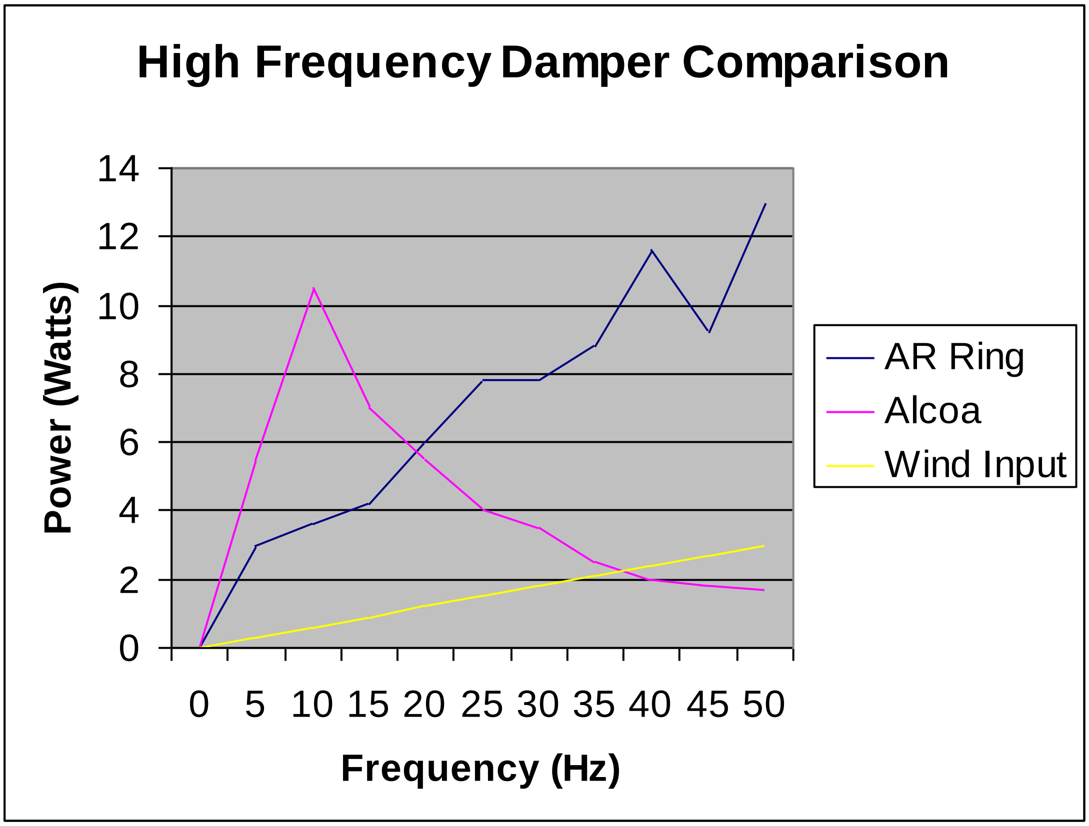
It also appears that more ALCOA dampers are required to protect a given cable span length and cable diameter. Other dampers are described below.

Photo #3 Mod IX AR DAMPER on guy cable

The family of “canister type” dampers consists of MOD VII (3Lb.), MOD VIII (10Lb.), Mod IX (5Lb.). These have aluminum enclosures with several loose galvanized steel washers inside. The impacts of these onto the inside walls of the enclosure create kinetic energy loss, or damping.

If one wishes to compare the performance of two different manufactured damper devices one should also try to compare them on the same basis. We have the results from testing the ALCOA damper at NEETRAC and from testing the AR RING damper at NEETRAC, both at vibration of 200mm/sec Velocity. While the ALCOA device is more than fifteen pounds heavier than the AR RING damper (32Lb v. 18Lb) it would make sense to compare each to a consistent basis. At 200mm/sec velocity this is the standard chosen by the IEEE as the safe limit of vibration for the power conductor. At that limit the power input to the conductor is the same. We have used the wind tunnel data reported by Farquharson & McHugh in IEEE Transactions, (1956) p871 as our basis for comparison of the two dampers. The data reveal that a span length of 1,000ft. and a conductor diameter of 1.5in. produces a straight line from the origin to a level of three watts power input at frequency of 50 cycles per second (Hz). The three graphs are shown below.

The characteristic peak power of the Stockbridge damper is evident. The broad band characteristic of the AR RING damper is evident. The power curve from the wind starts at zero and increases linearly to three watts at a frequency of 50 cycles per second for a conductor/cable diameter of 1.5in. on a span length of 1000ft. This same wind power input curve applies to a horizontal or to an inclined cable.



DISCUSSION

Each damper is compared for its performance on a span length of 1,000ft. and a cable diameter of 1.5in. The wind input has been calculated for the same conditions of cable diameter, span length, and vibration velocity at the IEEE limit of 200mm/sec. The weight of the ALCOA damper is 32Lb. The weight of the AR RING damper is 18Lb. It is further assumed that the damper is placed at the anti-node of a steel cable under a tension of 10% of ultimate strength, or 29,000Lb. The weight per unit length is 4.73Lb/ft. The assumed wind speed is 10mph. The calculated spacing for the damper is 60 inches from the cable end. Under those conditions each damper would be moving at the rate of 200mm/sec. maximum. The frequency of vibration is calculated at 25 cycles per second at 10mph wind speed.

When the wind speed is different than 10mph the anti-node moves away from the damper. For higher wind speeds it moves toward the support. For lower wind speeds it moves toward the tower. The two points at which the transverse velocity at the damper drops to 100mm/s, respectively, are 20in. and 100in. from the cable end. Tests were also made of these dampers at this reduced vibration velocity. The corresponding vibration frequencies are at eight and forty-two Hertz. The corresponding wind speeds are 3.3mph and 16.6mph. This is a spread of five to one, which could easily occur in the course of a single day.

The question is, "will the damper maintain sufficient power dissipation at the reduced vibration velocity of 100mm/sec while the cable is still vibrating at 200mm/sec?" An inspection of the previous graph reveals:

- At the low end of wind speed & frequency (8Hz) the two dampers have a significant margin over the wind input.

- At the high end of wind speed & frequency (42Hz) the AR RING Damper has increased its margin considerably above the wind input while the ALCOA damper has lost its margin altogether.

Because of insufficient coverage at the higher wind speeds
It may be necessary to use an additional ALCOA damper .

The shortfall of the ALCOA damper may be seen in greater detail in the accompanying table.

TABLE (1) Comparison of dampers at 100mm/sec vibration

Frequency(Hz)	Ring Damper	ALCOA Damper	Wind input
0	0	0	0
5	1.3watts	2.6watts	0.3watts
10	1.7	5.0	0.6
15	1.9	3.1	0.9
20	2.0	2.0	1.2
25	2.5	1.5	1.5
30	3.2	1.2	1.8
35	3.2	0.95	2.1
40	2.7	0.87	2.4

The Ring damper maintains a positive margin over the entire range of frequencies, while the ALCOA damper loses out to the wind at 25Hz, corresponding to 10mph wind speed for the 1.5in. diameter cable. It does indeed seem that another ALCOA damper would be required to restore the positive margin. One Ring damper is sufficient for this cable (1.5in.x1,000ft)

This also illustrates that while the damper motion is dropped to the 100mm/s level, the cable motion remains at 200mm/s. This is because the vibration loop is shorter at high frequencies and the anti-node moves away from the damper (toward the cable support). In terms of wave length at high frequency (42Hz) the wave length is about 11ft. and at low frequency (8Hz), the wave length is about 100ft.

The Scruton Number

There is another way to look at vibration damper effectiveness that has gained widespread popularity. It uses a non-dimensional parameter, known as the Scruton number, in honor of Christopher Scruton who introduced the concept in 1963. It has also been referred to as reduced damping and mu-delta parameter. It is essentially an energy ratio, namely, the ratio of the energy dissipated per cycle of vibration to the maximum kinetic energy of vibrating structure at its natural mode and frequency. In the case of a vibrating cable, since the energy dissipated in the cable itself is small, the Scruton number is a direct measure of the damper's ability to reduce the vibration. Dampers are usually tested in a laboratory at 200mm/sec. and 100mm/sec. It is useful to compare the two dampers, previously discussed, on the basis of their respective Scruton numbers over the range of frequencies tested, seen in the accompanying tables.

Table 2 Comparison Stockbridge damper and Ring damper at 200mm/sec.

	Energy per Cycle(W-s)		Scruton Number	
Frequency	Ring damper	ALCOA	Ring damper	ALCOA
5Hz	0.6	1.1	145	267
10	0.36	1.05	87	255
15	0.28	0.46	68	113
20	0.30	0.27	72	66
25	0.31	0.16	75	39
30	0.26	0.12	63	28
35	0.25	0.07	61	17
40	0.29	0.05	70	12
45	0.20	0.04	49	9
50	0.26	0.03	63	8

Scruton himself said, "`the maximum amplitude fell rapidly to a low value with the initial increase of damping (up to S=20) and decreased only slowly with further increases". Here, the Scruton number of 20 limits the vibration double amplitude to one twentieth the diameter of the circular cylinder.

The original paper by Scruton was published in Volume II, Wind Effects on Buildings and Structures, Symposium No. 16, National Physical Laboratory, Teddington, Middlesex, England, June 26-28, 1963. The above quote is found on page 804.

Thus, if one uses the criterion, S>20 for satisfactory performance, the above results indicate unsatisfactory performance above 35Hz for ALCOA damper.

Table 3 Comparison Stockbridge damper and Ring damper at 100mm/sec.

	Energy per Cycle (W-s)		Scruton Number	
Frequency	Ring Damper	ALCOA	Ring Damper	ALCOA
5Hz	0.26	0.52	63	126
10	0.17	0.50	41	121
15	0.13	0.20	31	50
20	0.10	0.10	24	24
25	0.10	0.06	24	14
30	0.10	0.04	26	10
35	0.09	0.03	22	7
40	0.07	0.02	16	5

Based on same criterion, S>20, the ALCOA Stockbridge damper fails the SCRUTON test at frequencies above 25Hz. The Ring damper fails at 40Hz.

These results are consistent with the previous analysis, based on wind input.

Additional Considerations

One item is the proper placement of the damper. This has become a subject of “black art” in the minds if some engineers. It is not all that much mystery. The placement of dampers should be the point where the vibration is the most severe. Simply stated it is the point where the vibration is the highest amplitude. In ordinary terms this is at the one-quarter wave length of the vibration. However, one needs to choose a wind speed (and therefore a frequency). It turns out that a wind speed of ten miles an hour is a good choice because this is 50% of the maximum wind limit where vibration is possible. For a one inch diameter cable this translates into a frequency of 36 cycles per second at ten miles per hour. For a two inch diameter cable it translates into a frequency of 18 cycles per second.

Above twenty miles per hour no vibration is possible – too much turbulence.

Having chosen this attachment point for design considerations, it means that there is only one point on the conductor (cable) that satisfies it. It is at the one-quarter wave-length distance away from the support point. In steel cables, at a tension of 10% this distance is forty inches for a one inch cable. It is 80in. for a two inch cable, etc. Many steel tower manufacturers use this tension limit for all guy levels.

What happens when the wind speed is different from ten miles per hour? It is quite simple. The chosen point for damper placement no longer is at the (optimum) one-quarter wave length point. The vibration velocity applied to the damper no longer is maximum. The vibration velocity is reduced to 50% or 100mm/s when the wind speed is either increased to 16.6mph or reduced to 3.3mph. This corresponds to a bandwidth of 133% based on the center frequency. It is important to realize that the bandwidth ratio is the same for ***any diameter. It is a ratio of five to one on maximum/minimum frequency.***

Thus, a vibration occurring on a cable or conductor having a damper placed at its end-point for control purposes will become less effective as the wind speed either ***increases or diminishes*** on either side of the design wind speed.

It is still better to have the damper, rather than not to have it.

Bandwidth is Important

In communications theory and practice bandwidth is paramount. Wide band means faster information transfer, more channels, better control…all the good things! It is no less important in vibration control. Wide bandwidth means quicker response, more control over a wider range of wind speeds, and less chance of fatigue damage.

The studies referred to here have demonstrated (i) wide bandwidth of impact dampers return higher energy dissipation per pound of damper, (ii) wide bandwidth of impact dampers having no resonant frequencies present no weakness to damage by heavy ice load or heavy hurricane load.

CONCLUDING REMARKS

While there is much more to this subject than has been covered here, it has been informative in respect to (i) what causes HF vibration, (ii) what types of vibration dampers are available, (iii) some relations among frequency, wind speed, wave length, vibration limits, and technical standards.

Wide band width is achieved with impact dampers that far exceeds bandwidth available with Stockbridge dampers. Design of impact dampers is more rugged, lighter weight, and capable of protecting longer span lengths per damper than Stockbridge dampers. A particular design of impact damper known as the Ring damper has been tested under vibration in two orthogonal directions and found to have broad band equality of response. A particular design of Stockbridge damper known as ALCOA damper has been tested in the same laboratory under the same vibration conditions and found to have a narrow band response characteristic. Tests were performed only in the vertical plane because the Stockbridge damper was not designed to respond in the horizontal plane. The tests show that the impact damper has superior damping capability over a wide range of frequencies and wind speeds.

APPENDIX

For test data on two AR DAMPER devices and one Stockbridge Damper go to www.arproducts.org, click on Test Data, go to Document 4.

For a detailed test report of Ring damper device, go to Document 6.

For more information on Ring damper, go to Installation, Broadcast Towers.