Waveguide Absorbers for Structural Damping

Eric E. Ungar

Acentech Incorporated, 33 Moulton Street, Cambridge, MA 02138

Abstract: Manfred Heckl investigated in 1961 the loss factor contributions that attached systems make to vibrating structures. He also carried out some experiments in which he attached damped strips to the edges of a plate, with the idea that plate vibrations would induce bending waves in the attached strips, which waves would remove energy from the plate vibrations. This application of what has come to be known as waveguide absorbers has since led to extensions and implementations of this concept.

INTRODUCTION

As part of a study of wave propagation on beam-plate systems (1) Manfred Heckl investigated the damping of beams that results from attached plates. In order to increase the damping of plates in some related experiments he attached strips of aluminum damping tape to the plate edges, with each strip connected to the plate only at one of its ends and the rest of the strip extending away from the plate edge in the plane of the plate. In this arrangement vibrations of the plate induced flexural waves in the aluminum tape strips, resulting in removal of vibrational energy from the plate. O. Bschorr (2) and his coworkers seized upon this idea of using wave-bearing structures to remove energy from vibrating systems, carried out some related analyses and experiments, and explored some applications. Although a 1984 study sponsored by the U.S. Air Force (3) investigated the applicability of "waveguide absorbers" to lightweight structures and some further related investigations have been undertaken since then at BBN Laboratories (4) and at the U.S. Naval Postgraduate School (5), relatively few noise and vibration control practitioners appear to be aware of the waveguide absorber concept. The present paper is intended as a step toward remedying this situation.

DAMPING EFFECT OF WAVEGUIDE ABSORBER

A waveguide absorber is a component, such as a damped rod or beam, in which vibrational (structure-borne sound) waves can be induced and dissipated, enabling an absorber that is attached to a vibrating structure to remove energy from the structure's vibrations. Unlike classical dynamic absorbers, which in essence are spring-mass systems that tend at their natural frequencies to reflect energy that impinges on their mounting points, waveguide absorbers act basically like ideal dampers that dissipate the energy that reaches them.

By applying the definition of loss factor in terms of the ratio of energy dissipation per radian to the vibrational energy present in a structure and by accounting for the effect of an attached system (e.g., a waveguide absorber) on the motion of the structure to which it is attached, one finds that the loss factor contribution $\eta$ that the attached absorber makes to the primary structure obeys (3)

$$\eta = \frac{R_A}{\omega M_S} \frac{V_S^2}{V_m^2}$$

where $Z_A = R_A + jX_A$ denotes the absorber's driving point impedance at its attachment point, $Z_S$ the driving-point impedance of the structure at the point where the absorber is attached, $M_S$ the total mass of the structure, and $\omega$ the radian frequency. $V_S$ represents the velocity amplitude of the structure's attachment point in absence of the absorber and $V_m$ denotes the surface-mass-weighted root-mean-square velocity amplitude of the structure, averaged over the entire structure.

As evident from the foregoing equation, a significant loss factor contribution may be obtained only if (a) the real part $R_A$ of the absorber's impedance is a reasonably large fraction of $\omega M_S$, which is the magnitude of the impedance of the structure as a rigid mass, (b) the velocity $V_S$ of attachment point on the structure is a considerable fraction of the root-mean-square velocity $V_m$ of the structure, and (c) the impedance of the absorber is not too large as compared to that of the structure. The equation thus implies that an absorber should be attached to the structure...
it is to damp at a point where the structure vibrates with a considerable amplitude and that the impedance of the absorber should be matched to that of the structure. From the first ratio of the equation one may also conclude that appropriately designed waveguide absorbers should be well suited to provide damping at low frequencies.

EXPERIMENTAL WAVEGUIDE ABSORBERS

At frequencies above a certain cut-off frequency the driving-point impedance of an infinitely long tapered rod or beam whose cross-sectional area decreases with distance from the driving point approaches that of an infinite uniform rod or beam with a cross-sectional area equal to that of the tapered rod at its driving point (2). The cut-off frequency depends on the severity of the taper; the more rapidly the cross-sectional area decreases with distance, the higher the cut-off frequency. If a tapered element is driven considerably below its cut-off frequency, it acts essentially like a mass; if it is driven considerably above its cut-off frequency, it acts much like a damper. Bschorr devised a number of experimental absorbers that made use of metal wave-bearing elements which were tapered to achieve weight savings, folded for the sake of compactness, and encapsulated in high-damping materials to obtain dissipation.

One type of absorber conceived by Bschorr consisted of a tapered rod that was twisted about its longitudinal axis, then bent into a shape somewhat like that of a helical spring, and potted in a high-damping polymer. This complicated configuration was chosen so that vibration applied in virtually any direction would generate longitudinal, torsional, and flexural waves – with each wave type capable of transporting energy. The resulting absorber was cylindrical with a diameter of about 5 cm, a height of 4 cm, and a weight of about \( \frac{1}{4} \) kg. Six absorbers of this kind, when attached to a 50 kg beam at judiciously selected points, were able to produce rather impressive loss factors (in excess of 0.02 over nearly three octaves) with a weight penalty of only about 3%.

Another type of absorber that was investigated consisted of an aluminum disc that was covered with a damping material and cut so as to constitute an array of strips that radiated outward from the center and had spiral shapes with areas that decreased with increasing distance from the center. The idea was to have vibrations that are applied at the center of the disc in the direction perpendicular to its plane make these strips vibrate in both flexure and torsion, so as to increase their energy transport and dissipation capabilities. Such discs were shown to be able at low frequencies to add at least ten times more damping to a light aluminum plate than conventional free-layer or constrained-layer damping treatments of the same weight.

CONCLUDING REMARKS

Waveguide absorbers have the potential for providing significant damping with comparatively little weight penalty. Their general nature implies that they tend to be relatively insensitive to temperature and to mechanical damage, that they can be made in compact form, that they readily can be encapsulated for environmental or contamination protection, and that they are likely to be useful for retrofit applications. However, they can provide significant damping only if they are applied at suitable locations and if their impedances are appropriately related to those of the structures they are to damp.

REFERENCES