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Rapid Position Switching in Radio Telescopes:
Structural Damping using a Constrained Layer Treatment

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Abstract

For the proposed NRAO MMA, calibration of the interferometric phase may require the antennas to be able to switch rapidly to and from a nearby calibration source. The ability to switch rapidly is limited by the natural resonant frequencies of key parts of the structure. The frequencies of these resonances may be changed, and the 'Q' of the oscillations changed in a controlled way, by the application of damping material to key members of the structure. The use of constrained damping layers gives the potential for greater control of these factors; the technology is already in use in applications ranging from computer disk drives to airplane turbines. This paper outlines the principles of the constrained damping layer treatment.

1. Introduction

When a structure is vibrated, there will be a reversible energy transfer in the system. The problems caused by structural vibration include buildup of strain level in the structural members and the positional instability of the structural body. Both aspects are undesirable to the antenna structure. In order to suppress the structural vibration, damping, either active or passive, is necessary. Damping works by enabling the system to dissipate energy from the periodic energy transfer in the vibration process. This results in a lower strain level and a more reliable structural performance. The constrained layer damping is a widely used passive damping treatment, which has been used in computer disk drives, auto engines, airplane turbine inlets and other fields. In this memo, only the principle of this treatment is introduced.

2. Uniform surface treatment

Unlike Young's moduli for elastic material, which are real numbers, for viscoelastic material the moduli may be expressed in a complex form. The real part of a complex modulus is the storage modulus and the imaginary part is the dissipating modulus. The complex expression is:

$$E_v = E_1 + iE_2$$

where E_1 is the storage modulus and E_2 is the dissipating modulus. When a layer of viscoelastic material of thickness t and width b is applied to the top of a structural member with thickness h, length L and Young's modulus E, which is also subjected to a fluctuating load of amplitude P(Fig. 1a), then the axial strain ε and P are related by the following formula:

$$P = b\ \varepsilon\ \{\ (Eh + E_1t)^2 + (\ E_2t)^2\ \}^{(1/2)}$$

The maximum strain energy stored during any one cycle is:

$$U_s = (Eh + E_1t)bL\varepsilon^2/2$$

and the energy dissipated is:

$$D_s = \pi\ E_2tbL\varepsilon^2$$

The loss factor of the entire structure is:

$$\eta_s = D_s/2\pi U_s = tE_2/(Eh+E_1t)$$

The storage modulus E_1 of most viscoelastic material is much less than that of the structure member, so the above formula can be simplified as:

$$\eta_s = E_2t/Eh$$

Since E_2 of the viscoelastic material is much smaller than Young's modulus of any constructional material, higher damping can only be achieved by adding large amount of high loss material.

3. Constrained layer treatment

Constrained layer treatment is a more efficient way to achieve a higher loss factor. The configuration of the constrained layer damping is shown in Fig. 1b. In Fig. 1 b, atop the viscoelastic layer is a cover sheet of thickness t_c and modulus E_c, and the cover sheet is restrained at one end only. In this way, the fluctuating load, P, induces a state of shear in the damping material layer. If no bending moment or other force are transferred to the cover sheet, the shear strain distribution in the shear layer will vary from zero at the fixed end to a maximum at the free end as:

$$\sigma = x\delta/tL$$

where δ is the tip displacement of the structural member due to the axial force. If the shear layer has a complex modulus $G = G_1 + iG_2$, the energy dissipated per cycle in the viscoelastic layer will be:

$$D_s = \pi G_2\delta^2Lb/3t$$

The maximum energy stored during the cycle is:

$$U_s = \{Eh/2 + G_1L^2/6t\}(b\delta^2/L)$$

Since G_1 is much less than E, there is negligible energy stored in the damping material. The loss factor is therefore:

$$\eta_s = \pi G_2L^2/3Eth$$

As t and h are much less than L, the constrained shear layer has the potential to produce much high levels damping than the uniform surface treatment.

The above analysis is for demonstration purposes. In reality, the influence of shear on the deformation of the cover sheet and the structural member cannot be ignored; in practice the energy dissipated is less than would be expected from the above formula. Also the thickness of the viscoelastic layer cannot be made arbitrarily small since it may cause failure of the shear layer or the cover sheet. In the design of the constrained layer damping, there are many other factors which have to be considered. Those factors are: the spectrum density of the excitation, the frequency related Young's modulus of the damping material, and the temperature related Young's modulus of the damping material. In other words, the design of the constrained layer damping is more complicated.

4. Multi constrained layer damping

Due to the limitation of thickness t, it is still difficult to create a high loss factor by using a single layer damping treatment. Greater added damping is possible by applying more layers of damping material and cover sheet. The multi-layer treatment has been used on the air inlet vanes of turbine engines for airplanes.

Fig. 2 shows a number of beam configurations where constrained layer damping is applied.

5. Manufacturers and designers of vibration damping

An important manufacturer of the viscoelastic material is the 3M Company. 3M can provide well calibrated viscoelastic damping sheets with various thicknesses. The price of the sheet material is about $25 per sq. yard. The address of 3M company is:

Vibration control system
3M Center, Building 230-1F-02
St. Paul MN 55144-1000
Tel 612-733-6199

Some design and analysis companies dealing with structural damping are:

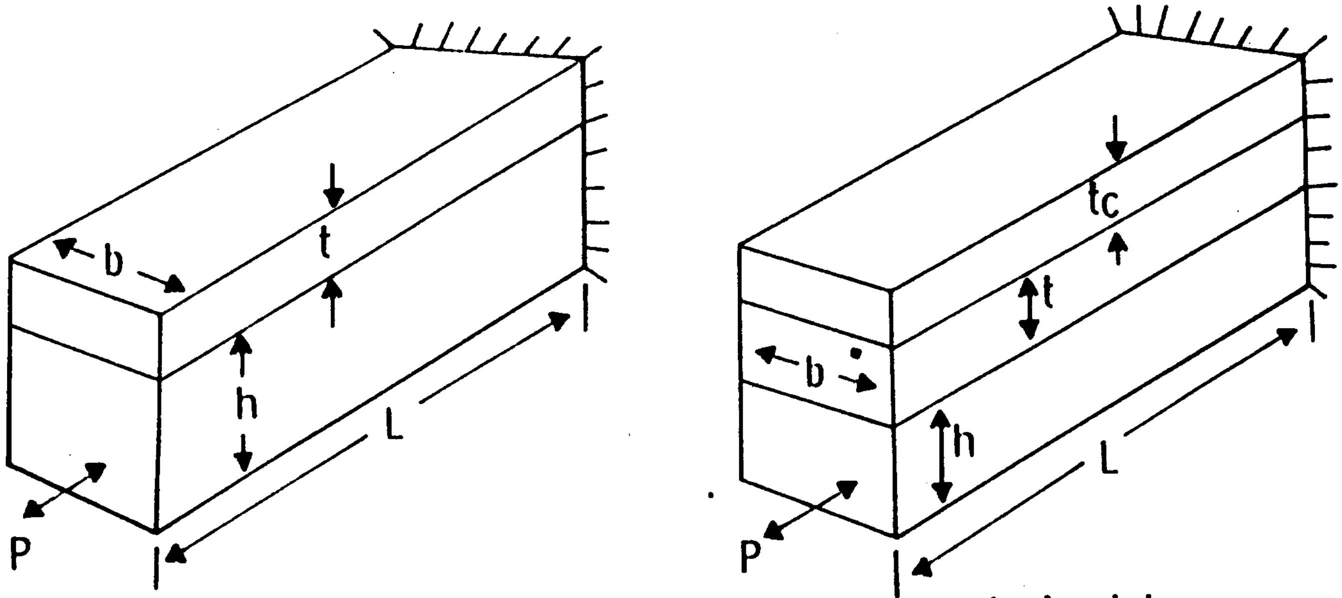
Vibration group
University of Dayton
Research Institute
Aerospace mechanics division
300 College Park
Dayton Ohio 45469-0112
Tel. 513-229-2644

CSA engineering, Inc.
2850 W bayshore Rd
Palo Alto CA 94303-3843
tel. 415-494-7351

Roush Anatrol
10895 Indico drive
Cincinnati OH 45241
tel. 513-793-8844

Reference:

Damping applications for vibration control, Edit, P.J.Torvik, The American Society of Mechanical Engineers, 1980.



a. Unconstrained Layer

b. Constrained Layer

Fig.1, Damping Treatments for Bars

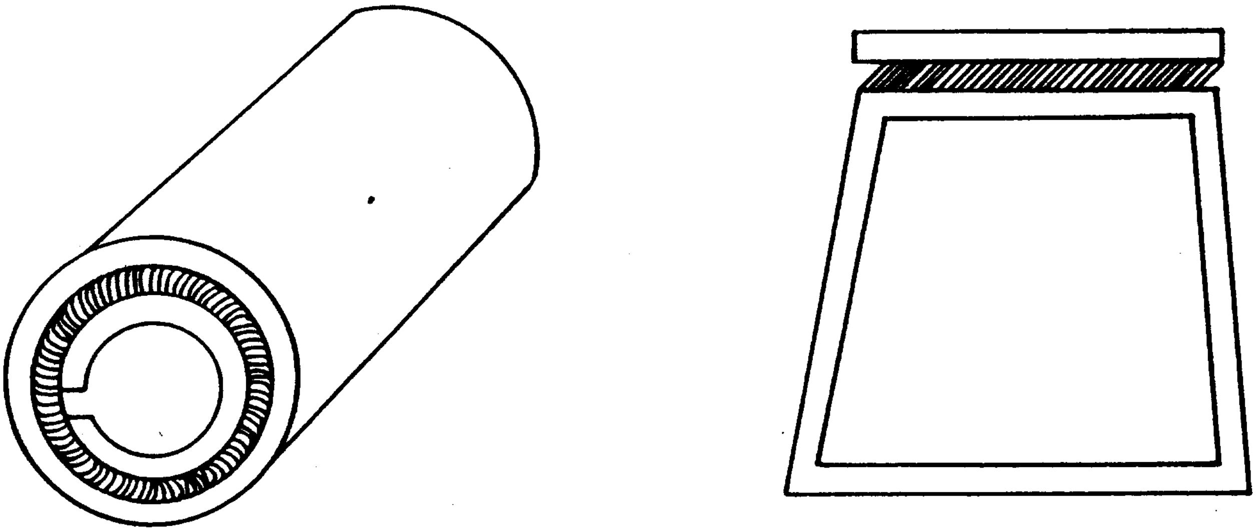


Fig.2 Some damped beam configurations.