SOME EXPERIMENTAL RESULTS FROM EVALUATION OF CONSTRAINED DAMPING LAYER STRUCTURES

by

C. A. Dahlquist
Minnesota Mining and Manufacturing Company
Minneapolis, Minnesota

The Minnesota Mining and Manufacturing Company has developed pressure sensitive tapes, and structures involving pressure sensitive tapes or pressure sensitive adhesives, for vibration damping. I wish to present to you some of the results obtained in evaluating these damping materials and to show you a comparison of measured and calculated damping factors.

In its simplest form the constrained damping layer takes the form shown in Figure 1. It consists of a tape with a flexible, but relatively non-stretchable backing--therefore, a high modulus backing--and a pressure sensitive adhesive. The adhesive is viscoelastic, and consequently can dissipate energy when work is done upon it.

I will refer to the tape backing as the constraining layer and the tape adhesive as the damping layer. Flexure in the plate produces a shearing action between the plate and the constraining layer. The cyclic shear in the adhesive causes energy dissipation to an extent which depends upon the "storage" shear modulus and the "loss" shear modulus of the adhesive. These quantities are frequency and temperature dependent. They are measurable with suitable equipment such as the Fitzgerald apparatus used in our laboratory.

The composite plate is therefore characterized by a complex bending stiffness, i.e., there will be an energy storage component to the bending stiffness and also an energy loss component. The ratio of these two, loss component/storage component, we will call η ,or loss factor. η , then, is an index of the damping which has been built into the structure by adding the constrained damping layer. It is directly relatable to other damping indices such as the Q of the system, log decrement, etc.

Kerwin (1) has analyzed the composite structure, and has evaluated the damping factor, η , for purely flexural waves, in terms of the bending modulus and dimensions of the plate, the storage and loss components of the shear modulus of the viscoelastic interlayer, and the stretching modulus and dimensions of the constraining layer. Thickness of the interlayer and mass per unit length of the composite structure also enter into the calculation.

Figure 2 shows the agreement between theory and experiment. Curve A represents variation in damping factor with frequency for a composite plate consisting of a 1/8 inch aluminum plate, a 0.0025 inch damping layer, and a 0.0055 inch aluminum foil as the constraining layer. The test procedure was similar to that of Kerwin (1). The damped plate was tested as a long thin strip so that vibration was predominantly true flexure. The circles represent measured values of η and the solid lines calculated values.

Curve B represents a composite beam consisting of 1/8 inch aluminum plate, 0.005 inch of pressure sensitive adhesive, and 0.008 inch aluminum foil as the constraining layer. Note that theory predicts the observed shift and improvement in damping.

The largest source of discrepancy between theory and experiment probably lies in the uncertainty of the measured values of the elastic constants of the adhesive. Variations in adhesive thickness and uncertainties in the elastic constants of the plate and foil are other contributing factors.

In Figure 3 we see how the damping factor varies with plate thickness when the constraining layer and damping layer combination is held constant. Here the points represent calculated values while the lines represent experimental results. Note that trends are again predicted correctly by theory and the agreement between theory and experiment is very good for the 0.090" and 0.125" plates. It is not as good for the 0.040" plate, but it was difficult to get reliable measurement of the damping factor on the thin plate.

Figure 4 shows the change in damping factor with change in thickness of the viscoelastic interlayer. The magnitude of shift corresponds to that which is predicted by theory, but the agreement between observed and calculated values is not as good as in the previous figures. This may be due to less reliable evaluation of the elastic constants of the adhesive (this is not the same adhesive as that of the previous figures and it has not been tested as thoroughly) or it may be due to error in measurement of the adhesive thickness.

One can augment the damping by using multilayers of tape (see Figure 5). This usually shifts the maximum damping to lower frequencies. Ross, Ungar, and Kerwin (2) have developed the theory for multilayer damping, and their scaling method for evaluating double layers was used to calculate the values represented by the black dots. Note again the theory correctly predicts the direction of shift but may fall a little short in predicting magnitude at the lower frequencies.

As you have probably suspected, the damping efficiency depends to a great extent on the ability of the damping layer to dissipate energy. Figure 6 shows the results obtained with three different pressure sensitive adhesives, other conditions of testing being the same. I want to hasten to point out that these do not necessarily represent optimum conditions for each adhesive. For example, in curve No. 3, there may be a bad mismatch of constraining layer and adhesive layer. Each damping problem must be carefully analyzed and the most efficient damping structure selected for that particular situation.

It should be pointed out also that one may have to sacrifice some damping performance at room temperature in order to get good performance over a broad range of temperature and frequency. Some of the most temperature- and frequency-sensitive adhesives may have excellent damping characteristics in a very limited environmental range.

Kerwin (3) has shown how one can magnify the shear strain in the damping layer, and hence greatly increase the damping efficiency, by inserting a spacer between the vibrating plate and the tape. Figure 7 illustrates one example of such a spacer. It consists of hollow inverted boxes which are rigidly bonded to the vibrating plate. The boxes are independent units, i.e., they are not joined along the sides or at the top. The damping tape is adhered to the upper-most faces of the boxes. When the plate bends, these spacers, being rigidly bonded to the plate, are deflected radially. This greatly magnifies the shear strain in the damping layer, and, since the damping increases as the square of the amplitude of the shear strain, there is a correspondingly large increase in damping. Typical data are shown in Figure 8.

The efficiency of the spacer depends upon its resistance to shear and bending--generally the more rigid it is the better will be the performance. This means that there must be some compromise between performance and weight, since the rigidity decreases as one reduces the amount of material in the spacer. Best results to date have been obtained with a glass reinforced plastic "waffle".

Even then we have not yet realized all of the theoretical potential of the spacer in the system shown in Figure 6. Note, however, that the spacer magnifies the damping equally over the entire range of frequency.

There are many other possible structures which can capitalize on this spacer concept for increasing damping. One of them utilizes a constrained foam bonded to the vibrating member by a pressure sensitive adhesive. Then one can take advantage of energy dissipation in the spacer as well as in the adhesive. Such a system has shown a great deal of promise for damping thin panels, and it has a decided advantage in ease of application.

The work on constrained damping systems has had many interesting consequences, but perhaps the outstanding one, and one that has been demonstrated time and time again, is the importance of engineering the damping material to the job requirements. It is possible, by mismatching the damping system and the vibrating member, to obtain very little benefit for the weight added. It is also possible to do an excellent job with a minimum of weight.

BIBLIOGRAPHY

1. Kerwin, E. M., Jr., J. Acoust. Soc. Am. <u>31</u> 952 (1959).
2. Ross, D., Ungar, E. E., and Kerwin, E. M., Jr., <u>Structural Damping</u> Section Three, Am. Soc. Mech. Eng. November 1959.
3. Kerwin, E. M., Jr., J. Acoust. Soc. Am. <u>31</u> 846 (1959).

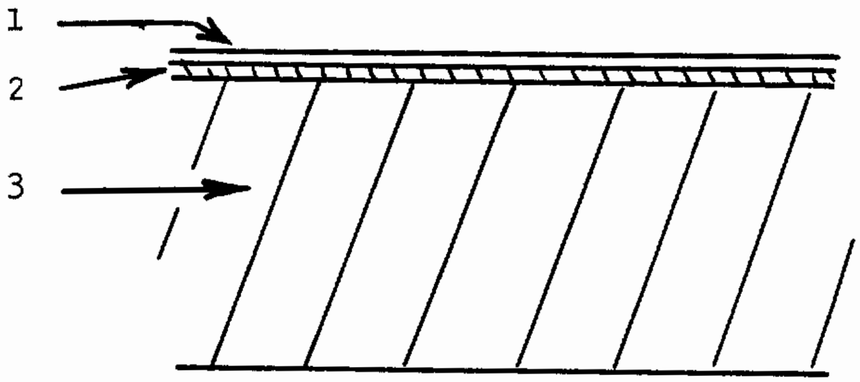

Figure 1 - Construction of Constraining Damping Tape
1 - Constraining Layer, 2 - Damping Layer
and 3 - Vibrating Plate

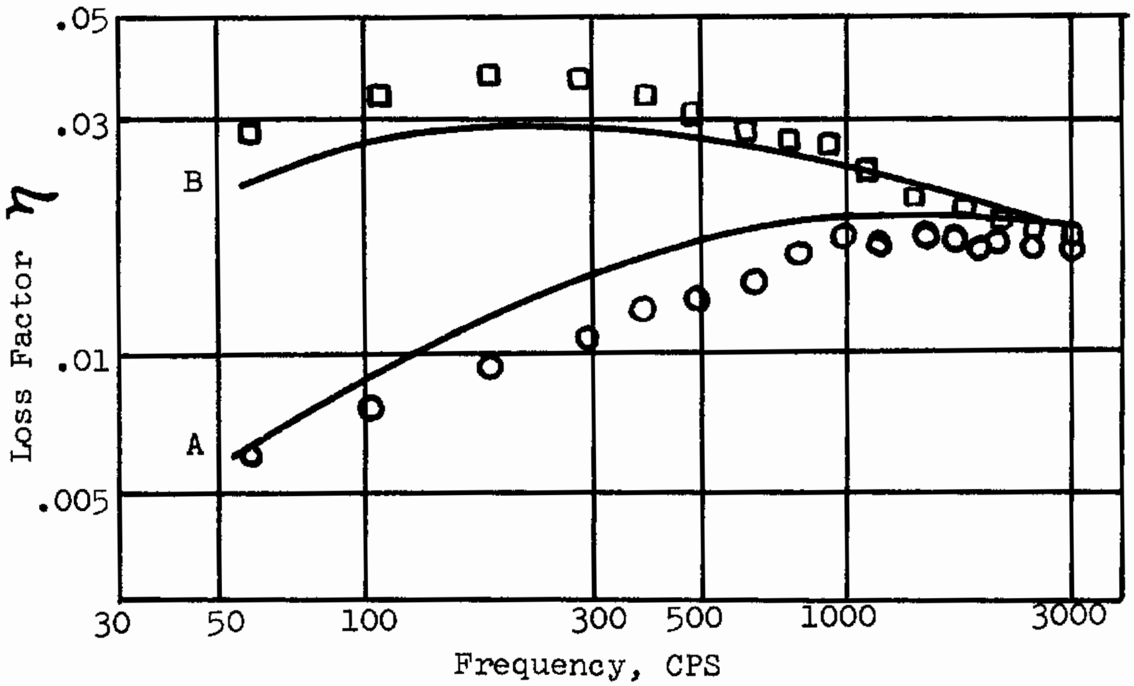

Figure 2 - Comparison of Calculated and Experimental
Damping Factors of Constrained Damping
Layers

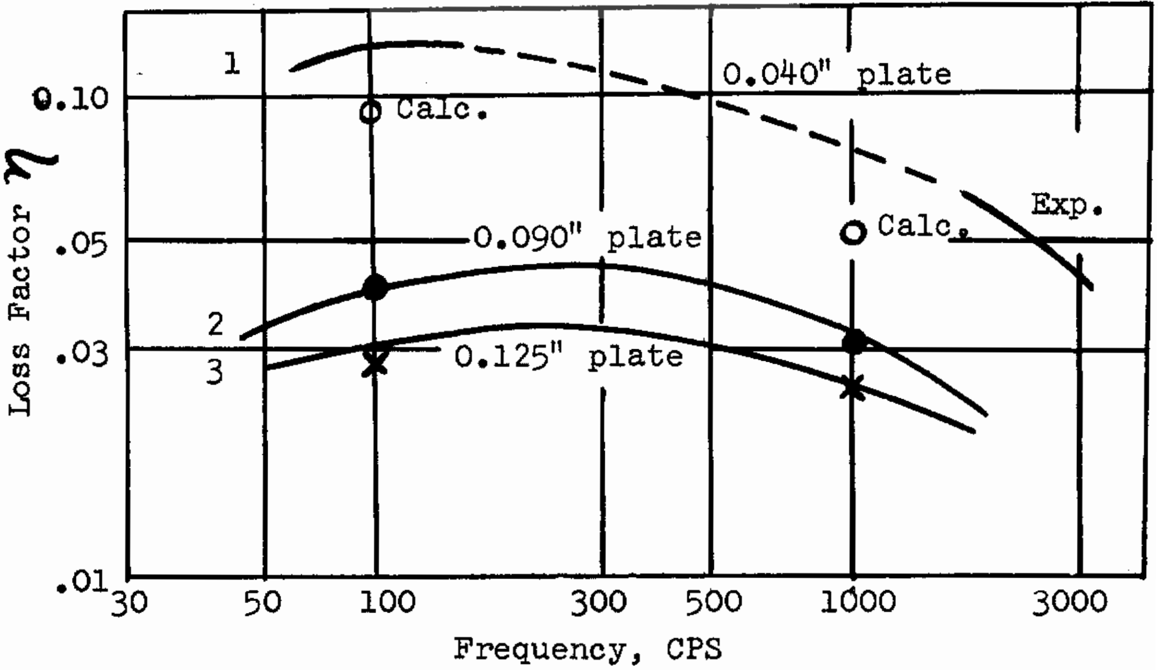

Figure 3 - Effect of Plate Thickness on Damping Factors (Constraining Layer 0.008" Al, Damping Layer 0.005")

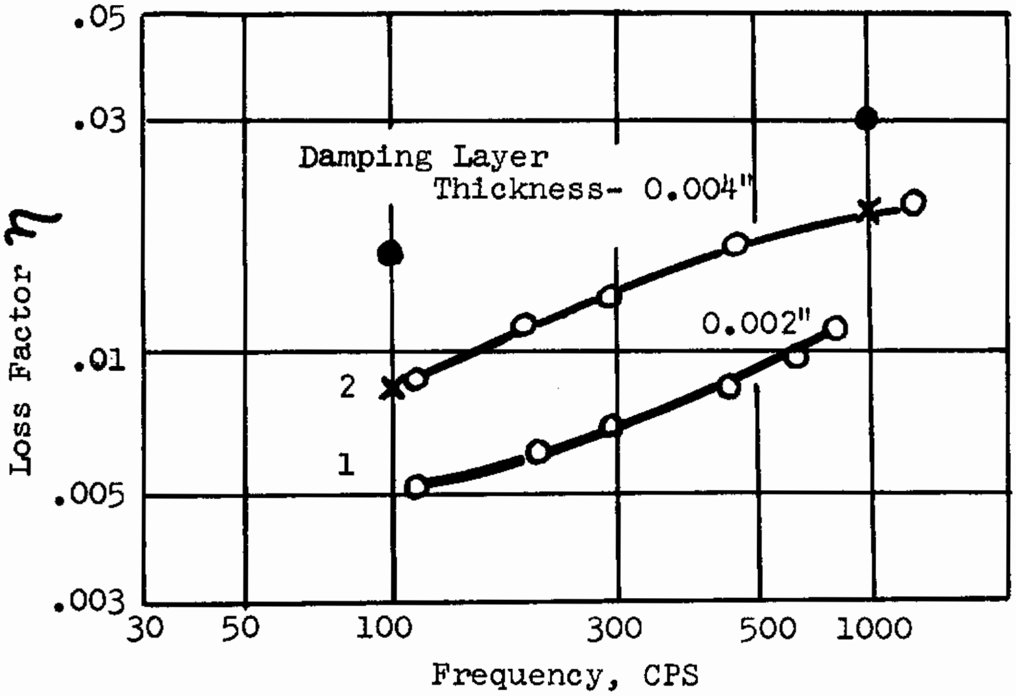

Figure 4 - Effect Of Damping Layer Thickness on Damping Factor (Constraining Layer 0.0055" Al.)

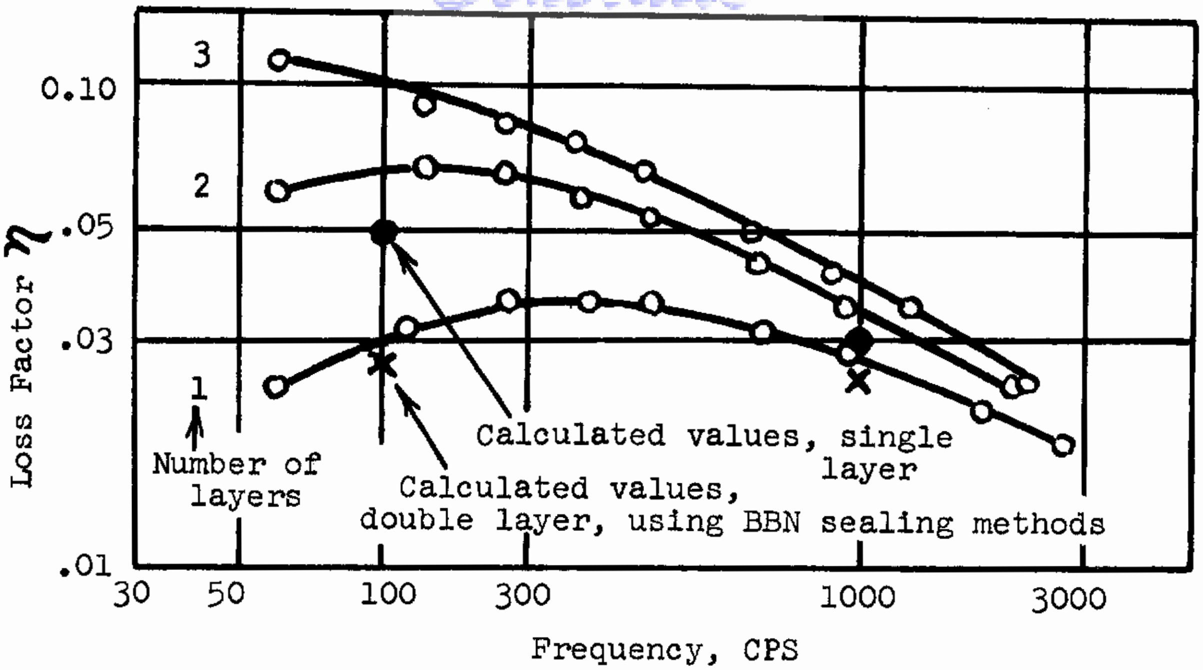

Figure 5 - Damping Factors for Single and Multiple Constrained Damping Layer (plate - 1/3" Al, constraining layer- 0.008" Al, damping layer thickness 0.005")

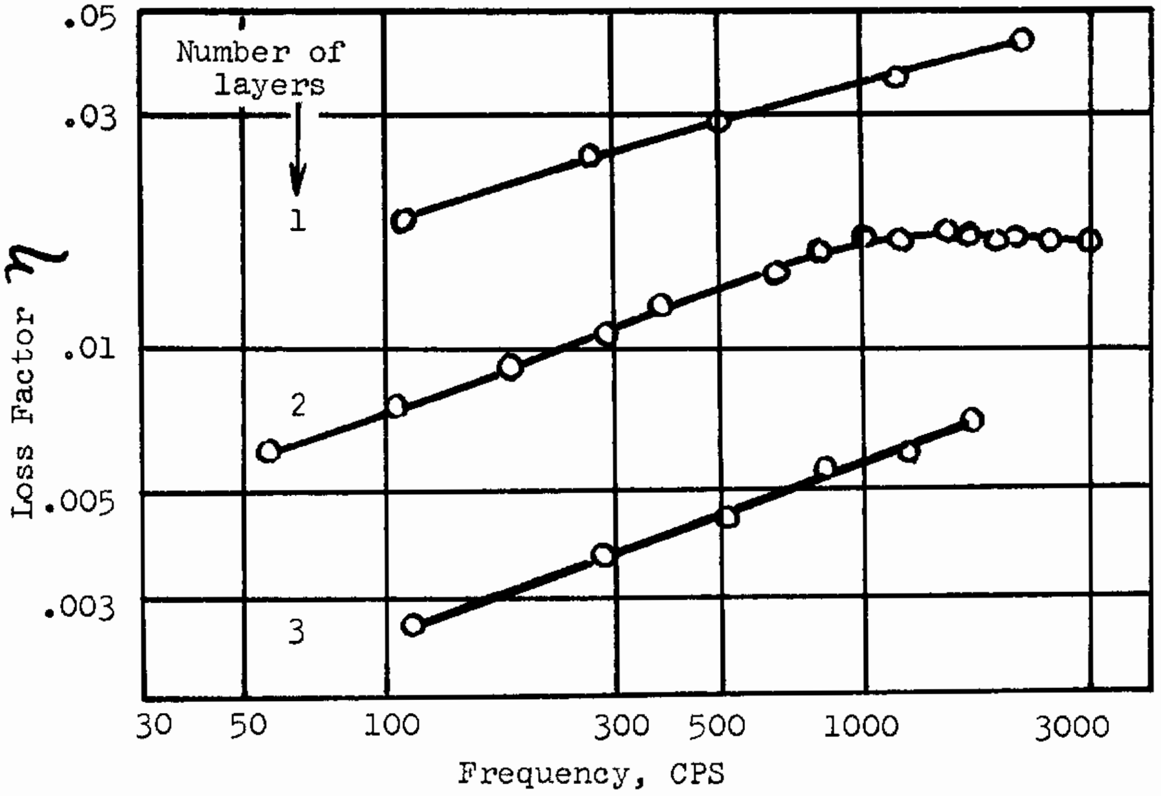

Figure 6 - Variation in Damping Factor as Viscoelastic Damping Layers Vary

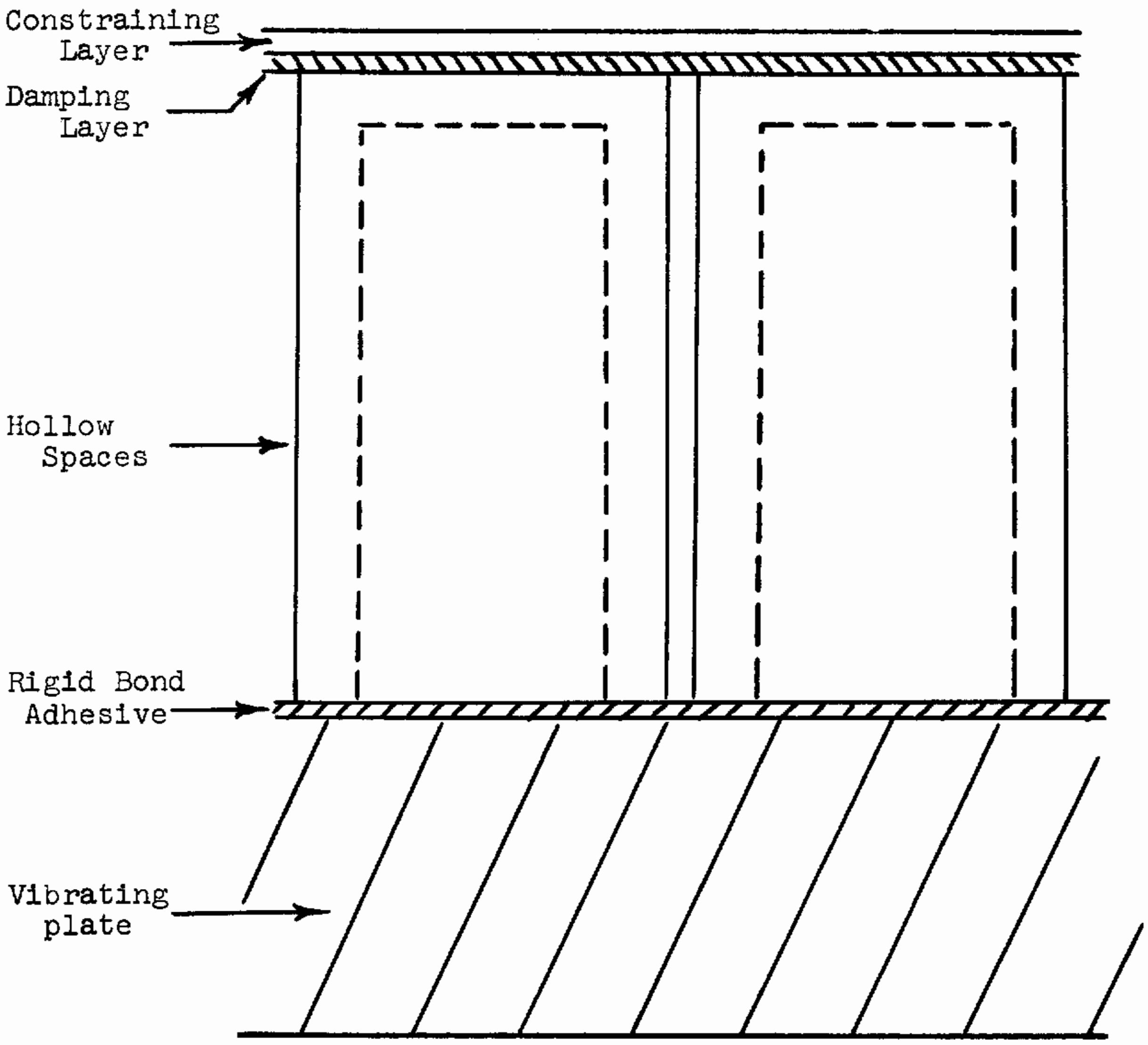

Figure 7 - Example of a Spacer Layer Construction

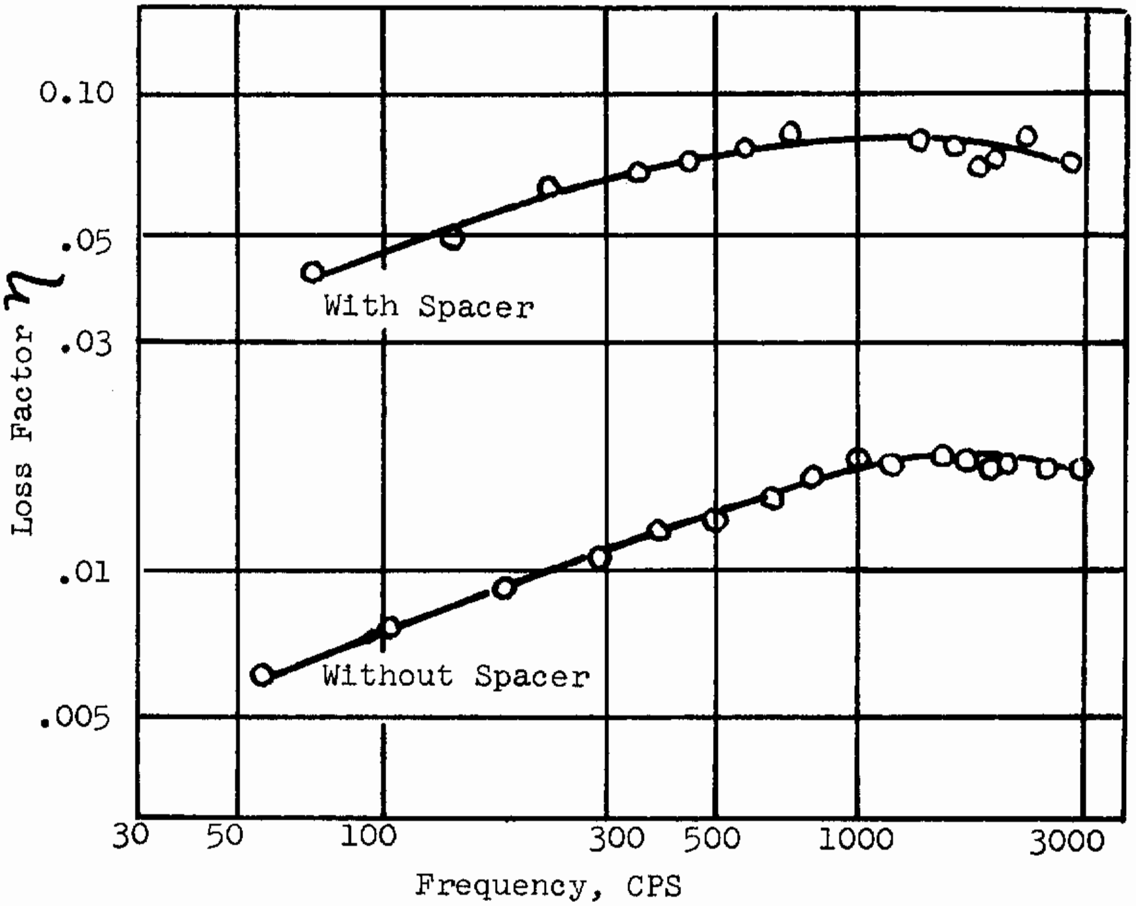

Figure 8 - Effect of Spacer on Damping Factor (plate - 1/8"Al, constraining layer-0.0055"Al, spacer-reinforced plastic waffle- 1/4" high, damping layer thickness - 0.0025")