The amount of damping in a given mode can be expressed in any of several different ways. In the present problem, the time rate of amplitude decay of free vibration was used. The last two columns of Table 2 give these data. A wide discrepancy is apparent between the calculated and test values for the decay rate, $d_n$, for beams 3 and 4. Of the several factors which could account for it, there are strong indications that the invalidity of the "small damping" assumption which is inherent in both the analytical and test procedure is primarily responsible. In both theory and test, it was assumed that the motion at a resonance was purely in the resonant mode. In the analytical development, motion in nonresonant modes was assumed small and neglected, while in the tests the total motion was measured and apparently nonresonant motion was significant. It is evident from the modal coefficients (Table 2), that the theory has been extended somewhat beyond its range of applicability; while the damping coefficients $H_n$ are smaller that the stiffness coefficients $K_n$, in some cases, they are not much smaller as is necessary for the theory to be accurate.

In view of the numerical results, it is clear that the use of this theory should be limited to beams with damping of a smaller magnitude. For beams of the type considered herein, it is likely that retention of the damping coupling terms would improve the accuracy, however, a more general theory in which neither the magnitude nor frequency-dependence of damping are restricted is a more desirable solution. A layered plate theory of this type, in which the core material behavior is described by the use of the linear theory of viscoelasticity, is currently being developed by the authors. Its application to problems of the present type should give much better results than the present theory. Consideration is also being given to devising improved testing procedures for cases where damping is heavy.

Conclusions

The results of this analysis, in which a free-free sandwich beam with viscoelastic core has been studied, extend those of a previous analysis by the authors [1] in which infinitesimal and simply supported beams were investigated in theory only. In the present paper, as in the previous one, it has been shown that damping capacity can be efficiently designed into a beam by using the damping material as an integral part of the beam, namely the core.

In the present case, a more general formulation has been given involving all admissible boundary conditions. Further, an experimental backup program has verified the applicability of the structural theory for predicting natural frequencies but indicated that a more refined theory is required to accurately predict the damping when it is of such a large magnitude.

References


DISCUSSION

C. W. Bert, D. J. Wilkins, and W. C. Crisman

There is considerable current interest in the analysis of damping in sandwich-type structures with shear-flexible cores. The authors omitted reference to some important previous research in this field [11-13].

The writers seriously question the assumption of a free-free beam without any attached mass, since in the experimental setup the mass of the vibration exciter and accelerometer do not appear to be negligible compared to the beam mass. Also, the use of suspension points located arbitrarily 1/2 in. from the ends is questioned. As was pointed out by James [13], to minimize energy losses at the suspension points, they should be located at the nodes (which can be determined experimentally by use of powder sprinkled on the beam during vibration in a vertical plane).

The aforementioned factors may have contributed to the discrepancies between the calculated and test values of the amplitude decay listed in the last two columns of Table 2. Previous investigators [11-13] obtained closer agreement. Perhaps the calculated and test decay for the elastomer-core beam data should not be compared, since it was noted in the text that the natural frequencies are different for different compounds. However, in the case of the PVC-core beams, although the agreement for the natural frequencies is reasonable, it is surprising that the measured vibration decays were much lower than calculated.

In the text, the slight discrepancies in the natural frequencies of the PVC-core beams are attributed to the shift in peak frequency as damping is increased. However, this decrease in frequency due to damping occurs only for dashpot damping (damping force linearly dependent on velocity only) and not for material damping of the Kimball-Lovell type [14] (damping force linearly dependent on ratio of velocity to frequency [15]).

In the analysis, it was tacitly assumed that the dynamic shear coefficient $K$ (such as first used by Timoshenko [16] in connection with homogeneous beams) was equal to unity. However, Yu [17, 18] has developed an analysis for computing $K$ for sandwich construction, which for the parameters involved here would yield a $K$-value less than unity.

In closing, it should be mentioned that the rotatory inertia could have been included in the analysis without increasing the complexity of its mathematical structure [19].

Additional References

17 Professor of Aerospace and Mechanical Engineering, University of Oklahoma, Norman, Okla. Mem. ASME.
18 Graduate Student, School of Aerospace and Mechanical Engineering, University of Oklahoma, Norman, Okla.
19 Research Engineer, University of Oklahoma Research Institute, Norman, Okla.
20 Numbers in brackets designate Additional References at end of this discussion.


**Authors’ Closure**

As the discussers have noted, the damping effectiveness of sandwich structures with shear-flexible cores has been of interest for some time, and several fine documents on the subject are available. However, the special problems arising in the analysis, testing, and fabrication of such structures when the core is made of a viscoelastic (rubber or plastic most often) material were intended as the focal point in the paper. When such is the case, the analytical treatment is complicated by a few factors: First, the damping force is, in general, neither a simple dashpot type force nor a Kimball-Lovell type, but has a frequency dependence which is more complex and varies from one material to another. (See Fig. 6 for two examples.) Consequently, the natural frequency-shift may be either an increase or a decrease and may not necessarily be small. Secondly, the magnitude of damping present in such structures is sometimes great enough to raise a question concerning the validity of normal mode theory (as customarily applied with the small damping assumption). Thus, the usual representations of damping effectiveness, which are based upon modal response, as well as customary testing techniques such as powder sprinkling become inaccurate since there are, strictly speaking, no normal modes and no nodes. Thirdly, the frequency-dependent dynamic properties of viscoelastic materials are sometimes sensitively affected by the proportions of ingredients as well as the conditions under which they are combined. Thus, the properties used in a theoretical analysis must assuredly be those of the same materials used to make the specimens.

To attempt to obtain better agreement between theory and test results, the authors intend to first re-do the experiments, paying special attention to material property accuracy and nullification of the effects of suspension cords and shaker inertia. Refinement in the shear coefficient and inclusion of rotatory inertia have already been studied and found to be unimportant for this problem.