Design for Damping

Performance of laminated metals can be modeled.

Product noise and vibration problems are often generated by the vibrating surfaces of sheet metal components that exhibit low levels of inherent material damping. Source excitation transmitted via an airborne or structure-borne path act to excite dynamic instabilities, or resonances, of these components, often amplifying levels to an excessive amount. This lightly damped, resonant behavior may cause actual high cycle fatigue and failure of critical components or simply result in the presence of unwanted vibration or radiated noise detected by the consumer.

One method of solution is to increase the level of damping to these sheet metal components by manufacturing them from damped laminate material instead of plain sheet metal. The laminate metal consists of two layers of sheet metal sandwiched together with a thin, energy absorbing viscoelastic core. The reduced vibration in the product is achieved by converting the vibration energy into heat energy dissipated by the viscoelastic material as the part is subject to cyclic oscillation.

Damping Mechanism

A typical laminate sheet consists of two rigid metal layers sandwiched together by a polymer, or viscoelastic core adhesive. As the structure is subject to cyclic vibratory stresses, the individual metal layers move relative to each other, resulting in a shearing action imparted to the core material. This polymer core does more than just bond the laminate together. It also provides the mechanism that creates the damping effect, as these shear strains are converted to heat energy within viscoelastic material.

Viscoelasticity

As the name of this class of materials implies, viscoelastic materials possess both elastic and viscous properties. For a purely elastic material, all the energy stored in the sample during loading is returned when the load is removed. Furthermore, the displacement of the sample responds immediately, and in-phase, to the cyclic load. Conversely, for a purely *viscous* material, no energy is returned after the load is removed. The input stress is lost to "pure damping" as the vibratory energy is transferred to internal heat energy.

for all others that do not fall into one of the above extreme classifications, we call viscoelastic materials. Some of the energy stored in a viscoelastic system is recovered upon removal of the load, and the remainder is dissipated by the material in the form of heat. ***Fig. 1*** illustrates the relationship between stress and strain for a viscoelastic material subject to cyclic loading.

Modeling Techniques

Laminated metal material offers an effective method to increase the inherent level of damping in sheet-metal components. To assist the product designer considering the use of laminated metal material in place of traditional sheet metal, various practical modeling techniques are available that can be used both as a damping prediction and design optimization tool. Optimization of the laminate construction, as with all constrained layer type treatments, is a function of other parameters in addition to the actual properties of the viscoelastic material. This complexity offers more design flexibility as the thickness and type of the damping core as well as the constraining layers can be altered to optimize effectiveness of the laminated metal product.

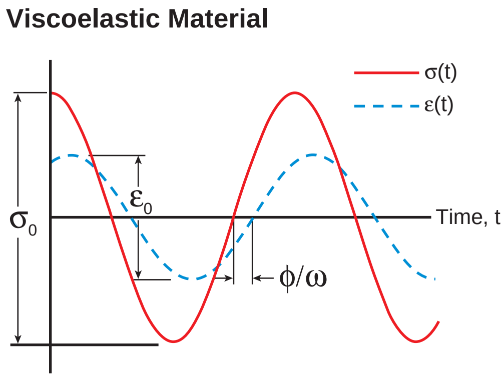

Fig. 1. *Cyclic Stress and Strain Curves vs. Time for Various Materials*

Two specific approaches are available to help assist in the selection and design of viscoelastic-based damping treatments.

Simplified RKU

One approach is to simplify a real world component down to an equivalent 3-layer beam or plate system. This was first suggested by Ross, Kerwin, Ungar, and the RKU method uses a fourth order differential equation for a uniform beam with the sandwich construction of the 3-layer laminate system represented as an equivalent complex stiffness. The equation for the flexural rigidity, EI, of this system has been reported in many technical references, and is therefore not duplicated here. The most common assumption made when using this method is that the mode shapes of the theoretical structure are sinusoidal in nature,

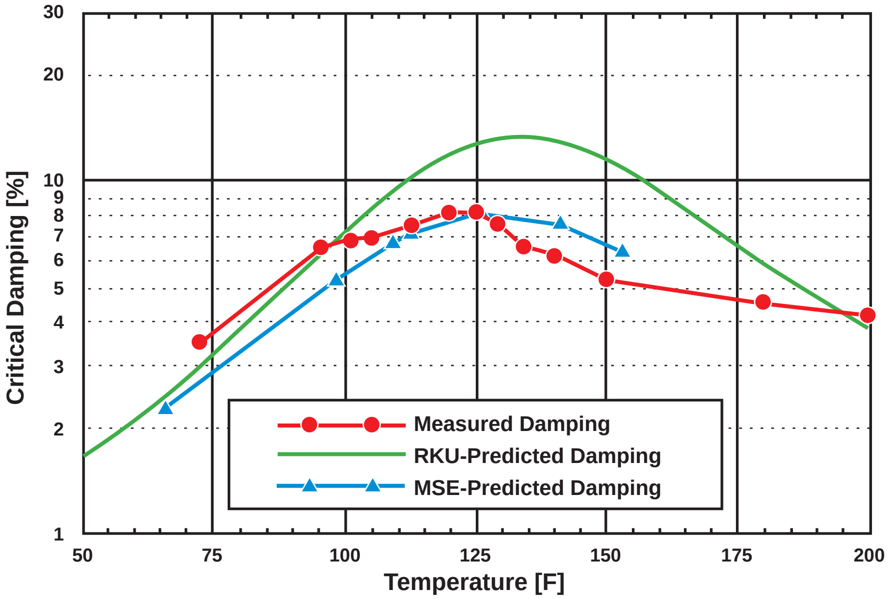

Fig. 2. *Comparison of Measured Damping vs. Predicted Damping using various modeling techniques*

therefore implying a simply-supported boundary condition. When using this approach with other boundary conditions, which may be necessary in working with actual structures, approximations must be made in the results depending on the mode shape in question.

The RKU method is better suited as a damping *indicator* as opposed to a precise damping predictor when applied to complex, real world structures. The goal is to use this simplified method to develop design trends that will lead to the selection of a damping material, constraining layers, and thickness which yield optimized damping performance.

Modal Strain Energy

Another prediction method known as the Modal Strain Energy (MSE) approach utilizes a finite element analysis (FEA) representation of a structure as the basis for of modeling the damping effect. This method has been shown to be an accurate predictor of damping levels in structures comprising layers of elastic and viscoelastic elements. The MSE principle states that the ratio of composite system loss factor to the viscoelastic material loss factor for a given mode of vibration can be estimated from the ratio of elastic strain energy in the viscoelastic elements to the total strain energy in the model for a given mode. This is shown mathematically in the following equation:

$$\eta_s^n = \eta_{VEM} \frac{U_{VEM}^n}{U_{Total}^n}$$

η_s^n	is the system damping for the nth mode of vibration
η_{VEM}	is the material damping for the appropriate frequency and temperature
U_{VEM}^n	is the elastic strain energy stored in the viscoelastic core for the nth mode
U_{Total}^n	is the total elastic strain energy for nth mode shape

Typically, the MSE approach is used in conjunction with an undamped, normal modes analysis to compute the strain energy ratio. The strain energies are determined from the relative mode shapes. It is assumed that the viscoelastic properties are linear in terms of the dynamic strain rate.

Application

In a recent design application, the RKU and MSE techniques were applied in estimating the constrained-layer damping effect of a typical add-on damping treatment applied to a vibrating cover component. These design prediction methods were used to (1) select the best viscoelastic core material, and (2) define the optimized treatment geometry to maximize the damping performance for the temperature range of interest. The predicted damping values are shown using both modeling techniques plotted against actual measured results in Figure 2.

The illustration shows some of the limitations of the simplified RKU approach. It is clear that hte true boundary conditions and mounting effects of the front cover are not well represented by the theoretical, simply-supported plate structure used in the RKU method as the predicted damping level has been over estimated and shifted in temperature. However, this method is an effective tool for initial screening of various candidate materials and design iterations, narrowing down the options to a few choices. The MSE approach can then be employed to generate more accurate results, as is demonstrated above. This approach shows much better correlation with actual behavior both in terms of damping level and temperature trends.

Although this is an example of an add-on constrained layer type treatment, the same techniques can be used in working with laminated material for sheet metal components.

— Paul J. Macioce

Paul J. Macioce is engineering manager, NVH Products Group, Roush Industries, Inc., Roush Anatrol Division, Livonia, Mich.