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Effect of Viscoelastic Material Thickness of Damping Treatment Behavior on Gearbox

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Abstract: The problem of reducing the level of vibration in system arises in various branches of engineering, technology, and industry. Therefore, there is a need for vibration control. Several techniques are utilized either to limit or alter the vibration response of system. During recent years, there has been considerable interest in the practical implementation of these vibration-control systems. The most commonly used method of increasing the damping is to include highly damped polymeric material at key locations onto the structure. In thins study discuss about thickness of damping material effect on damping treatments. And by literature review and from experimental result it found that the most efficient damping treatment (Constraint Layer Damping, CLD) efficient damping treatment as compare to the Free-layer or Extensional Damping. CLD change its behavior after certain thickness of damping material under the constant thickness of structural and constrained material thickness. CLD efficiency became worst than the Free-layer or Extensional Damping. It does analyze by modal analysis in FEM software (ANSYS).

Keywords: Al, damping, damping treatments, FEM, steel, vibration

INTRODUCTION

The problem of reducing the level of vibration in system arises in various branches of engineering, technology, and industry. The sources of detrimental vibrations significantly influence the mission performance, effectiveness, and accuracy of operation. Therefore, there is a need for vibration control. Several techniques are utilized either to limit or alter the vibration response of system. During recent years, there has been considerable interest in the practical implementation of these vibration-control systems (De Silva, 2007).

When an unacceptable vibration problem needs to be controlled, it is firstly desirable and often necessary to understand its whole nature. Then it can solve, if an added damping system is to be effective, the increased damping must be significantly larger than the initial damping. Then, it must be decided whether the problem would be best solved by passive or active control methods. The passive control involves modification of the stiffness, mass and damping of the vibration system to make the system less responsive to its vibratory environment. If the unacceptable vibration and acoustics is dominated by one or more resonance of the structure, it can be often adequately controlled by increasing the damping of the system.

For most applications, noise and vibration can be controlled using four methods: Absorption, use of barriers and enclosures, Structural Damping and Vibration Isolation (Jennifer, 2001). Most non-resonant vibration and acoustics problems cannot be solved by the damping treatment. If an added damping system is to be adequate, the increased damping must be incomparably larger than the initial damping. The most commonly used method of increasing the damping is to include highly damped polymeric material at key locations onto the structure. The structure and polymer must interact with one another in such a way as to cause the polymer to dissipate as much energy as possible. In usual procedure, there are two kinds of damping treatments for vibration and acoustics control.

Passive damping as a technology has been leading in the non-commercial aerospace industry since the early 1960s. Advances in the material technology along with newer and more efficient analytical and experimental

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tools for modeling the dynamical behavior of materials and structures have led to many applications.

The use of surface damping treatments in the automotive, commercial airplane, appliance and other industries has only been in recent years. The eventual application into these industries is made possible by the innovation in manufacturing processes which are cost-effective and are suitable for high volume production. Multilayer damped laminates consisting of two metal skins with a viscoelastic core can now be manufactured by a continuous process in coil form using existing equipment and technology rather than by the conventional laminating press procedure (Rao, 2003).

The first is called extensional damping treatment. This treatment is also referred to as the unconstrained-or free-layer damping treatment. The treatment is coated on one or both sides of a structure, so that whenever the structure is subjected to flex, the damping material will be subjected to tension-compression deformation. The second one is named as shear type of damping treatment. For a given weight, the shear type of damping treatment is more efficient than the extensional damping treatment. However, this efficiency is balanced by greater complication in analysis and application. The treatment is similar to the unconstrained-layer type, except the viscoelastic material is constrained by another layer. Therefore, whenever the structure is subjected to flex, the extra layer will constrain the viscoelastic material and force it to deform in shear. The maximum shear deformation in the middle layer is a function of the modulus and the thickness of the constraining layer, the thickness and the damping material and the wavelength of vibration in addition to the properties of the damping material.

The real description of the damping force associated with the dissipation of energy is difficult. It may be a function of the displacement, velocity, stress or other factors. Most of the mechanisms which dissipate energy with a vibrating system are non-linear and conform neither to the linear viscous nor to the linear hysteretic damping (Denys, 2000). However, ideal damping models can be conceived which will often permit a satisfactory approximation.

In this study, a bit review about damping and common categories of damping material in engineering. The kinds of damping treatment are described. After that, elaborate which damping treatment is more suitable. Finally found that some key changes after the application of damping material in damping treatment. There is not much literature review in this study about, modal analysis, damping, damping classification, and damping material. The readers are referred to review articles and research articles (Ciric and Ognjanovic, 2007; http://en.wikipedia.org/wiki/Modal_analysis_using_FEM.; Jimin and Zhi-Fang, 2001; Win-Jin *et al.*, 2003; Wong *et al*., 2009; Jean-Marie *et al*., 2008; Gounaris and Anifantis, 1999; Ioana and Ronald, 1999; De Silva, 2007; Horr and Schmidt, 1996; Ansys memo, 2000; Darrell and Juan, 1992).

DAMPING

Damping is the energy dissipation of a material or system under cyclic stress. Three main types of damping are present in any mechanical system:

Type of damping: Three main types of damping are present in any mechanical system;

- Internal damping
- Structural damping
- Fluid damping

Internal damping: Internal damping is caused by microstructure defects-impurities, grain boundaries, thermo elastic effects, eddy-current effects in ferromagnetic materials, dislocation motion in metals and chain motion in polymers. Besides, there are two types of internal damping: viscoelastic damping and hysteretic damping.

Structural damping: Rubbing friction or contact among different elements in a mechanical system causes structural damping. Since the dissipation of energy of depends on the particular characteristics of the mechanical system, it is very difficult to define a model that represents perfectly structural damping. The Coulomb-friction model is as a rule used to describe energy dissipation caused by rubbing friction. Regarding structural damping (caused by contact or impact at joints), energy dissipation is determined by means of the coefficient of restitution of the two components that are in contact. Structural damping is usually estimated by means of measuring but the measured values represent the total damping is the mechanical system. Consequently it is necessary to estimate the values for the other types of damping and to subtract them from the measured value in order to obtain a value of structural damping. Structural damping is much greater than internal damping and it represents a large portion of energy dissipation in mechanical structures.

Fluid damping: When the material is immersed in a fluid and there is relative motion between the fluid and the material, as a result the latter is subjected to a drag force. This force causes an energy dissipation that is known as fluid damping.

Damping materials: Although all materials exhibit a certain amount of damping, many (steel, aluminum, magnesium and glass) have so little internal damping that their resonant behavior makes them effective sound radiators. By bringing structures of these materials into intimate contact with a highly damped, dynamically stiff material, it is possible to control these resonances.

The common damping materials in use, many are viscoelastic; i.e., is, they are capable of storing strain energy when deformed, while dissipating a portion of this energy through hysteresis. Several types are available in sheet form. Some are adhesive in nature and others are enamel-like for use at high temperatures.

Since there are several types of damping but most of damping materials in the market provided by various manufactures belongs to hysteretic damping. The damping treatment technique is important in vibration control.

Damping treatment: A damping treatment consists of any material (or combination of materials) applied to a component to increase its ability to dissipate mechanical energy. It is most often useful when applied to a structure that is forced to vibrate at or near its natural (resonant) frequencies, is acted on by forces made up of many frequency components, is subjected to impacts or other transient forces, or transmits vibration to noise-radiating surfaces (Horr and Schmidt, 1996). In practice, there are two kinds of damping treatments for vibration control:

- Free-layer or Extensional Damping
- Constrained-Layer Damping (CLD)

Free-layer or extensional damping: The first is called extensional damping treatment. This treatment is also referred as the unconstrained-or free-layer damping treatment. It is one of the simplest forms of material application. It shows in Fig. 1. The material is simply attached with a strong bonding agent to one or both sides of a structure's surface. Alternatively, the material may be toweled onto the surface, or the structure may be dipped into a vat of heat-liquefied material that hardens upon cooling.

Energy is dissipated as a result of extension and compression of the damping material under flexural stress from the base structure see in Fig. 2. Damping increases with damping layer thickness. Changing the composition of a damping material may also alter its effectiveness (Horr and Schmidt, 1996).

Constrained-layer damping: The second one is named as shear type of damping treatment or Constrained-Layer Damping (CLD). It's usually used for very stiff structures. A "sandwich" is formed by laminating the base layer to the damping layer and adding a third constraining layer (Fig. 3). Typically, the constraining layer is of the same material as the base layer, but exceptions are common.

In this sandwiched construction, when the system flexes during vibration, the damping material layer is forced into shape that shears adjacent material sections. This alternating shear strain in the CLD material dissipates the vibration as low-grade frictional heat, shows in Fig. 4.

Fig. 1: Free-layer or extension damping construction (croos-section)

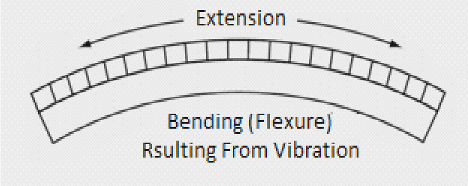

Fig. 2: Energy dissipated as result of extension of damping material

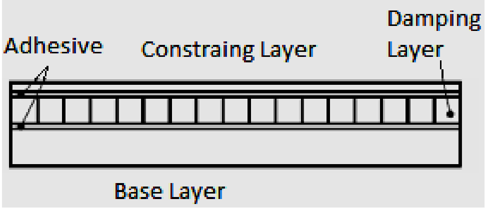

Fig. 3: Constrained-layer construction (cross-section)

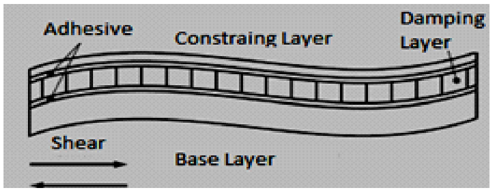

Fig. 4: System under vibration (magnified)

METHODOLOGY

The modal analysis is determined the natural frequencies and mode shapes of the structure. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. Modal analysis in the ANSYS family of products is a linear analysis. Any nonlinearity, such as plasticity and contact (gap) elements, are ignored even if they are defined. The several mode-extraction methods can be chosen like: Block Lanczos, subspace, PCG Lancos, reduced, unsymmetric, damped, and QR Damped. The damped and QR damped methods allow you to include damping in the structure. The QR Damped method also

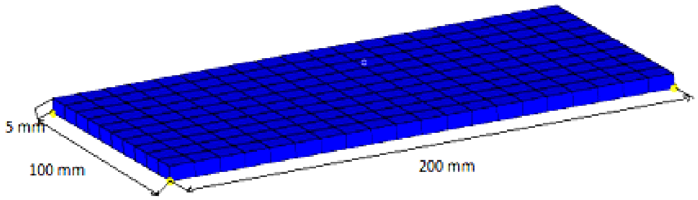

Fig. 5: Simple model

allows for unsymmetrical damping and stiffness matrices (ANSYS release11.0).

ANSYS dynamic analysis represented by Eq. (1) to carry out, the damping effect of the damping matrix [C]. In this equation, the damping force is the viscous damping model; this type of damping force is proportional to frequency. Of this issue to be marked in lag damping material damping is the scope, size and frequency independent of its value, so considering to when dealing with different damping parameter:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = F \tag{1}$$

The damping matrix C in ANSYS may be used in harmonic, damped modal and transient analysis as well as substructure generation. In its most general form it is:

$$[C] = \alpha[M] + \beta[K] + \sum_{j=1}^{N_{mat}}\left[K_j\right] + \beta_c[K] + \left[C_\zeta\right] + \sum_{k=1}^{N_{ele}}\left[C_k\right] \tag{2}$$

where,

α: Constant mass matrix multiplier (input on ALPHAD command)

[M]: Mass matrix

β: Constant stiffness matrix multiplier (input on BETAD command)

β_j: Constant stiffness matrix multiplier (input on MP, DAMP command) material-dependent damping. It is noted that different damping parameters are defined for different types of analysis when using the material-dependent damping. For example, MP, DAMP in a spectrum analysis specifies a material-dependent damping ratio ζ, not β.

βc: Variable stiffness matrix multiplier; (available for the harmonic response analysis, is used to give a constant damping ratio, regardless of frequency):

$$\beta_c = \frac{\zeta}{\pi f} = \frac{2\zeta}{\omega} = \frac{\eta}{\zeta} \tag{3}$$

ζ : Constant damping ration (input on DMPRAT command). From Eq. (3), the damping ratio ζ should be $\eta/_2$ where η the loss factor is.

f : Frequency in the range between f_b (beginning frequency) and f_e (end frequency);

[C_ζ] : Frenquency-dependent damping matrix [C_ζ] may be calculated from the specified ζ_r (damping ratio for mode shape r) and is never explicitly computed:

$$\{u_r\}^T\left[C_\zeta\right]\{u_r\} = 4\pi f_r \zeta_r \tag{4}$$

$\{u_r\}$: The r^{th} mode shape

f_r : Frequency associated with mode shape r:

$$\zeta_r = \zeta + \zeta_{mr} \tag{5}$$

ζ_{mr}: Constant damping ratio (input on DMPRAT command)

ζ_{mr}: Modal damping ratio for mode shape r (input on MDAMP command)

$[C_k]$: Element damping matrix

CASE STUDY-1

Efficient damping treatment: Analyze the efficient damping treatment using simple steel model. By modal analysis both treatment has been analyzed under same conditions.

The Fig. 5 is the pictorial representation of the discrete model of the simple model (200×100×5 mm, respectively). The properties of the simple model are tabulated in Table 1.

In this case damping material applied on whole width of simple model thickness of the damping material from 1 to 24 mm. determined the damping ratio by using the modal analysis with QR damped methods. It analyzed that damping ratio increased by increasing the thickness of damping material in both cases, (free-layer damping treatment and constrained-layer damping treatment). But it's observed that, constrained-layer damping treatment more efficient than the free-layer damping treatment. The obtained result of (free-layer damping) is tabulated in Table 2 and graphically representation is shown in. Fig. 6.

Constrained-layer treatment has been analyzed at same conditions; it's found more efficient then free-layer treatment. As shown in Fig. 7 damping ratio increases

Table 1: Material properties

Properties	Values
Density, ρ	(7.8e^{-9} Ton/mm^{3})
Young's modulus of elasticity, E	(2e^{5} MPa)
Poisson ratio, υ	0.3

Table 2: Free-layer damping treatment (simple model)

SA-3 thickness (mm)	Damping ratio
1	8.89e^{-04}
2	2.36e^{-03}
3	4.54e^{-03}
4	7.53e^{-03}
5	1.15e^{-02}
6	1.64e^{-02}
7	2.23e^{-02}
8	2.93e^{-02}
9	3.73e^{-02}
10	4.64e^{-02}
12	6.76e^{-02}
16	1.21e^{-01}
20	1.84e^{-01}
24	2.52e^{-01}

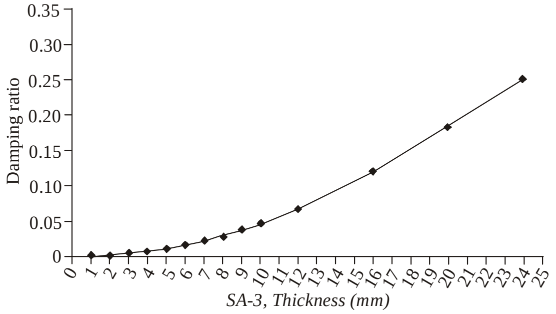

Fig. 6: Graphical representation of free layer damping treatment (simple model)

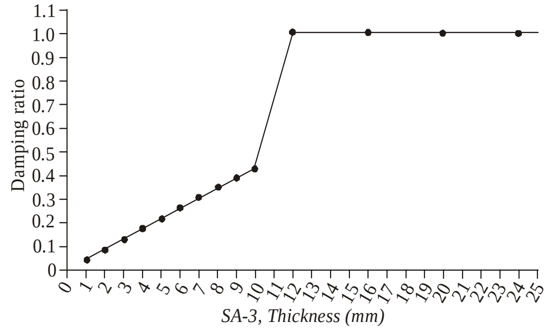

Fig. 7: Graphical representation of CLD- damping treatment (simple model)

rapidly as compared to free-layer damping result plotted in Fig. 6.

The constrained-layer damping results are graphically represented in Fig. 7 and tabulated in Table 3. The obtained results are satisfied that Constrained-layer damping layer treatment is more efficient than the free-layer damping treatment.

Table 3: CLD-treatment (simple model)

SA-3 thickness (mm)	Damping ratio
1	3.96e^{-02}
2	7.96e^{-02}
3	1.23e^{-01}
4	1.68e^{-01}
5	2.14e^{-01}
6	2.59e^{-01}
7	3.02e^{-01}
8	3.45e^{-01}
9	3.85e^{-01}
10	4.23e^{-01}
12	1.00e^{+00}
16	1.00e^{+00}
20	1.00e^{+00}
24	1.00e^{+00}

Table 4: Damping material properties at temp. 25ºC and freq. 241.32 Hz

Properties	Values
Density, ρ	(1.75e^{-9} Ton/mm^{3})
Young's modulus of elasticity, E	(500 MPa)
Poisson ratio, υ	0.49
Loss factor, η	0.85
DAMP $\left(\eta/_{2\pi f}\right)$	5.61e^{-04}

CASE STUDY-2

In this case the damping material applies on top cover of gearbox casing to control vibration. The application of damping material on gearbox has been determined by the model analysis. Damping material has to apply on, at maximum elastic strain intensity on structure, or also on maximum displacements nodes in extract mode shape. It is analyzed that the applications of damping have to be applied on the top wall of upper cover of gearbox housing.

Damping material has been applied on the top wall of gearbox housing cover, thickness of damping material vary from 1 to 24 mm at temperature 25ºC and frequency 241.32 Hz. The properties of damping material are tabulated in Table 4.

The thickness of constrained (Al) is 2 mm, but thickness of damping material change from 1 and 24 mm. The properties of Aluminum are; Density (ρ) 2.7e-9 ton/mm3, Poisson ratio (υ) 0.35 and Young's Modulus of Elasticity (E) 7e4 MPa. The Fig. 8 is the pictorial representation of the application of damping material on gearbox top cover.

The obtained results show on Table 5 and graphical representation on Fig. 9. It is analyzed that after certain thickness of damping material, damping ratio of the system is going to decrease or it can say that constrained-layer damping treatment behaves like free-layer damping treatment.

It is observed that from 1 to 9 mm thickness of damping material, damping ratio gradually increasing. But from 10 to 24 mm thickness of damping material, the damping ratios are less than the damping ratio of 1 mm

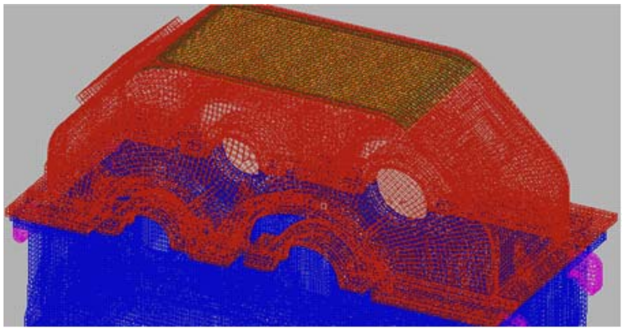

Fig. 8a: Application damping material on gearbox (wire frame)

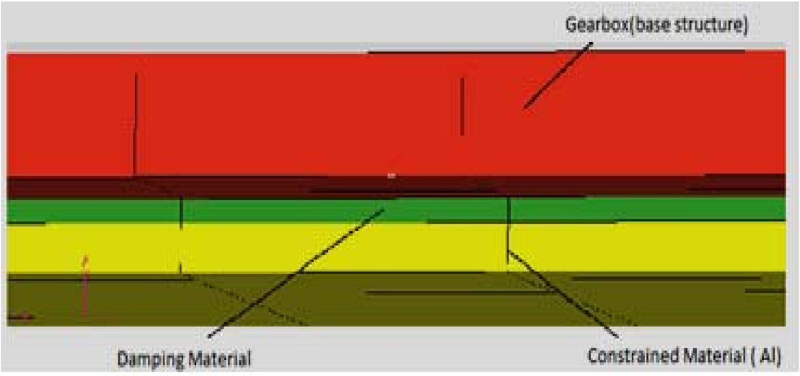

Fig. 8b: Application damping material (shaded)

Table 5: Constrain-layer damping treatment gearbox housing

SA-3 thickness (mm)	Damping ratio
1	$2.53e^{-02}$
2	$4.59e^{-02}$
3	$6.62e^{-02}$
4	$8.61e^{-02}$
5	$1.06e^{-01}$
6	$1.25e^{-01}$
7	$1.45e^{-01}$
8	$1.64e^{-01}$
9	$1.83e^{-01}$
10	$4.88e^{-03}$
12	$4.90e^{-03}$
16	$4.88e^{-03}$
20	$4.87e^{-03}$
24	$4.96e^{-03}$

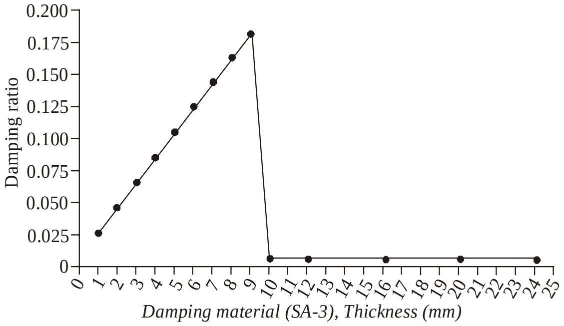

Fig. 9: Constrained-layer damping (gearbox housing)

thickness of damping material. As the result is shown in the Table 5, there is only a difference of 1 mm thickness from 9 to 10 mm but damping ratios change rapidly.

It shows that at a certain thickness of damping material the constrained material (Al) is negligible and constrained-layer damping treatment will behave like free-layer damping treatment.

CONCLUSION

Damping analysis (Modal analysis using QR damped method) was performed to determine the suitable damping treatment. Suitable damping treatment was analyzed for the application of chosen damping material. It was concluded from analysis that constrained-layer damping treatment was more efficient than free-layer damping treatment. And conclude that the thickness of damping material is important in vibration and noise control. But also the thicknesses of damping material have serious effect on damping treatment. After certain level of thicknesses of damping material it change the behavior of the damping treatment.

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