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The Damping Materials Selection and Topology Optimization of Body Floor

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Abstract: the damping materials has been widely used in vibration and noise reduction of automotive body , the automobile body damping materials almost are viscoelastic damping materials, due to the viscoelastic damping materials are both viscous and elastic characteristics, Under the effect of alternating stress the part of energy is converted to heat energy consume, another part of energy will be stored.This paper mainly study the relationship that viscoelastic damping material damping factor changing with temperature and frequency, than,to choose more suitable for body, topology optimization was carried out on the selection of damping material at the same time,optimize the location to the layout of the damping materials, use as little as possible of damping materials meet the requirements of vibration noise reduction effect.
Keywords: viscoelastic damping materials;Body floor;Vibration and noise reduction;Topology optimization

I. INTRODUCTION

Interior structure of the low-frequency noise is mainly from the vibration plate composed of a number of thin-walled body structure radiation. In the thin-walled plate surface of the additional damping material damping composite structure can be improved to improve the plate structure radiated noise level, and because of the viscoelastic damping material, in a relatively wide range of frequencies restrain vibration and noise purposes, so damping material large number of applications, the paper on the structure of the main body through the study of viscoelastic damping material loss factor with the relationship between the frequency and temperature variations damping material selection, the choice of good material, based on the position of the paving materials optimization.

1.The viscoelastic damping material properties

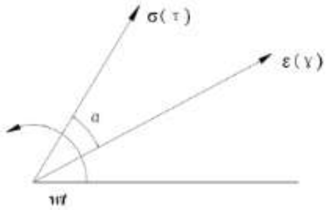
1.1 The constitutive relations of viscoelastic damping material expression Stress-strain relationship of viscoelastic damping materials generally Boltamann solid integral model can be used, for one dimensional stress and strain：

$$\sigma(t) = \int_0^t G_1(t-\tau)\dot{\varepsilon}(\tau)d\tau + G_1(t) * \varepsilon(0) = G_1(t) * \dot{\varepsilon}(t) + G_1(t)\varepsilon(0) \quad (1\text{-}1)$$

In the formula, $\sigma(t)$ and $\varepsilon(t)$ denote stress and strain; $G_1(t)$ for the relaxation function, when $-\infty < t < 0$, $G_1(t) = \varepsilon(t) = 0$; $*$ symbol denotes convolution.

1.2 Dynamic Characteristics Of Viscoelastic Damping Materials

The performance of viscoelastic damping materials including physical and mechanical properties and dynamic mechanical properties.The selection of viscoelastic damping materials should focus on the dynamic mechanical properties.Due to the viscoelastc material both has a dual characteristic of viscous fluid and elastic solids, the dynamic mechanical properties and elastic material also different, therefore, under the action of alternating stress, the stress strain curve is different from that of elastic material.For elastic material, after applying alternating stress, the internal stress and strain is almost at the same time to increase or decrease.Illustrate that phase is consistent or close, stress-strain curve is shown as a straight line.And strain lagging behind the stress of viscoelastic damping materials, the lag of the phase Angle for α , as shown in figure 1.1**.**Stress-strain curve of viscoelastic materials is an elliptic hysteresis curve, as shown in figure 1.2.



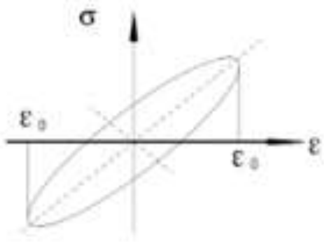


Figure 1-1 viscoelastic damping materials lag phase Angle α **Figure1-2** oval hysteresis curve viscoelastic damping materials

Oval area surrounded by the hysteresis curve means structural vibration viscoelastic material after the vibration energy dissipation, when viscoelastic materials under tension and compression stress and compressive stress, tension and compression deformation curve is expressed as its stress and strain relations:

$$\sigma = \sigma_0 e^{i\omega t} \quad (1\text{-}2)$$

$$\varepsilon = \varepsilon_0 e^{i(\omega t-\alpha)} \quad (1\text{-}3)$$

Complex modal method is to describe a method of viscoelastic damping material performance, in some ways than the generalized differential model or generalized standard model is convenient.According to the complex modulus definition (tensile modulus):

$$E^* = \frac{\sigma}{\varepsilon} = \frac{\sigma_0}{\varepsilon_0} e^{i\alpha} = E(\cos\alpha + i\sin\alpha)$$

Or:

$$E^* = iE^{"} + E^{'} = E^{'}(1+i\eta) \quad (1\text{-}4)$$

Among them, η is the loss factor of viscoelastic damping material, also known as loss tangent or damping coefficient, it is one of the important indicators to measure dissipation energy of damping materials, $\eta = E^{"} / E^{'}$,commonly used material damping loss factor of 0.2-5.0, if the loss factor of the structure is larger than 2.0 (or the modal damping ratio ξ_C> 1.0), the structure for overdamping structure, under dynamic load excitation structure will not occur the reciprocating vibration; E^* is tensile modulus of viscoelastic damping materials. $E^{'}$ is the real component tensile modulus, also known as storage which can stretch modulus, $E^{'} = E\cos\alpha$; $E^{"}$ the imaginary part of tensile modulus of viscoelastic damping materials, it determines the size of the energy loss of viscoelastic damping materials,also known as the energy consumption $E^{"} = E\sin\alpha$.

If viscoelastic materials by shear deformation, the shear stress-strain relationship curves can be expressed as (similar to the expression of pressure during the) :

$$\tau = \tau_0 e^{i\omega t} \quad (1\text{-}5)$$

$$\gamma = \gamma_0 e^{i(\omega t-\alpha)} \quad (1\text{-}6)$$

Shear modulus is:

$$G^* = \frac{\tau}{\gamma} = \frac{\tau_0}{\gamma_0} e^{i\alpha} = G(\cos\alpha + i\sin\alpha) \quad (1\text{-}7)$$

Or: $G^* = iG^{''} + G^{'} = G^{'}(1 + i\eta)$,

$$\eta = G^{''} / G^{'} \quad (1\text{-}8)$$

Among them, G^* are complex shear modulus of viscoelastic damping materials; $G^{'}$ is the real component shear modulus,also known as storage can shear modulus, $G^{'} = G\cos\alpha$; $G^{''}$ the imaginary part of shear modulus of viscoelastic damping materials,it decided to viscoelastic damping material is converted into heat energy dissipation, also known as the energy consumption, $G^{''} = G\sin\alpha$.

Engineering design process, based on viscoelastic damping materials in the actual structure of the stress state to decide to use shear modulus, when the tensile modulus, young's modulus, shear modulus and the relationship between the tensile modulus as follows:

$$E = 2G(1 + \mu) \quad (1\text{-}9)$$

Among them, μ for the poisson's ratio, general metal material poisson's ratio is 0.25-0.35, and poisson ratio of viscoelastic damping materials is 0.45 to 0.5.

Per unit volume of damping materials under the action of alternating stress and strain of work, that is ΔW , a vibration period of energy loss or damping can use said:

$$\Delta W = \iint \tau d\gamma dv = \pi\tau_0\gamma_0\alpha = \pi\gamma_0^2 G^*$$

Or: $$\Delta W = \pi\varepsilon_0^2 E^{''} \quad (1\text{-}10)$$

Maximum elastic energy, that is, within a week of total strain energy W:

$$W = \frac{1}{2}\gamma_0^2 G^{'}$$

Or: $$W = \frac{1}{2}\varepsilon_0^2 E^{'} \quad (1\text{-}11)$$

So dissipation can be with storage is as follows:

$$\frac{\Delta W}{W} = 2\pi\tan\alpha = 2\pi\eta$$

That is:

$$\eta = \frac{\Delta W}{2\pi W} \quad (1\text{-}12)$$

By type show that the loss factor of viscoelastic damping materials for each week vibration dissipation of vibration energy and the ratio of the maximum strain energy (energy).And a week can as the vibration energy dissipation damping vibration, therefore the greater the damping can be said the greater the value of loss factor of viscoelastic damping materials.

II. THE VISCOELASTIC DAMPING MATERIALS VARY WITH TEMPERATURE AND FREQUENCY CHARACTERISTICS

As a kind of polymer materials, the damping of viscoelastic materials depend on many factors, such as molecular structure, molecular friction between and motions, additives, composition, etc.

In the process of movement, elastic material can reserve energy and released energy,and not waste energy.Mark the main index of elastic material is young's modulus *E*.Self-adhesive materials can not reserve energy, but energy consumption.Describe the viscous material loss factor η is the main index.Viscoelastic material and "flexibility" and "sticky" characteristics, so describe the main indicators of viscoelastic material is young's modulus *E* and loss factor η.The main effect of damping material reducing vibration noise reduction associated with loss factor η, within a certain frequency the greater the loss factor η of damping materials, the more vibration energy is consumption, the better of vibration noise.

Here are two kinds of damping materials vary with temperature and frequency curve.

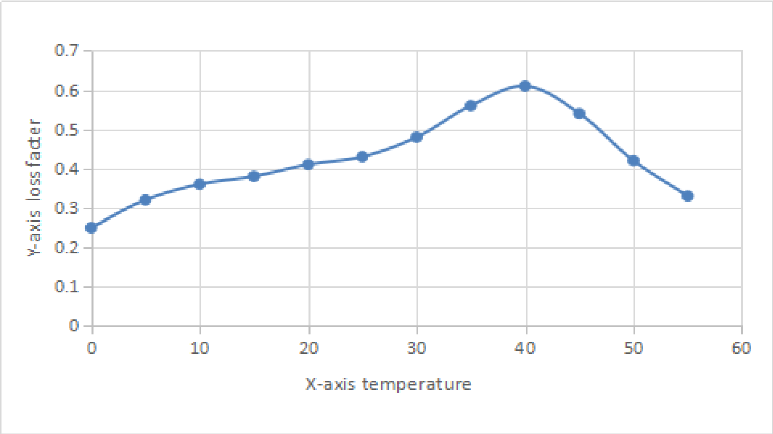


Figure 2-1 the relationship between the original car damping materials the loss factor with temperature (frequency 10Hz)

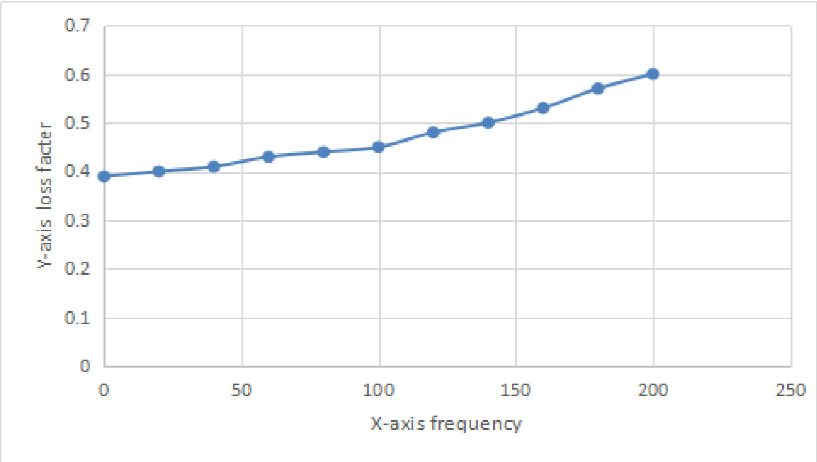


Figure 2-2 the relationship between original car damping material loss factor and the frequency (temperature 25 degrees)

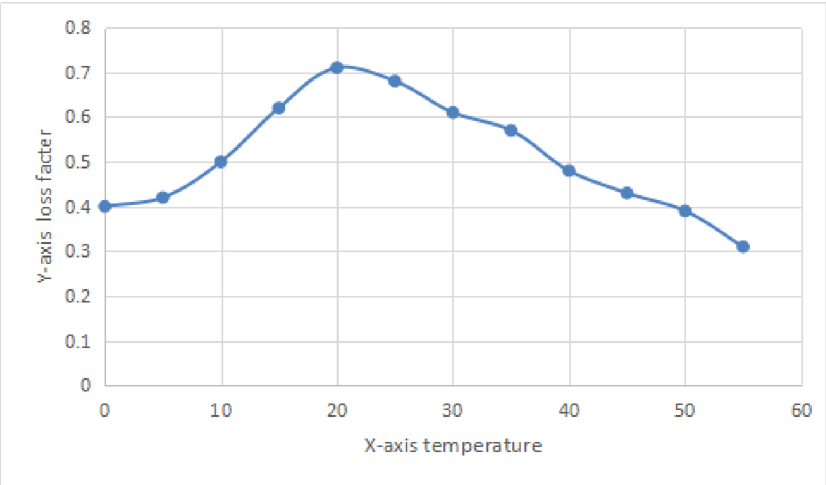


Figure 2-3 the relationship between Dy - 1 damping material loss factor with temperature (frequency 10 Hz)

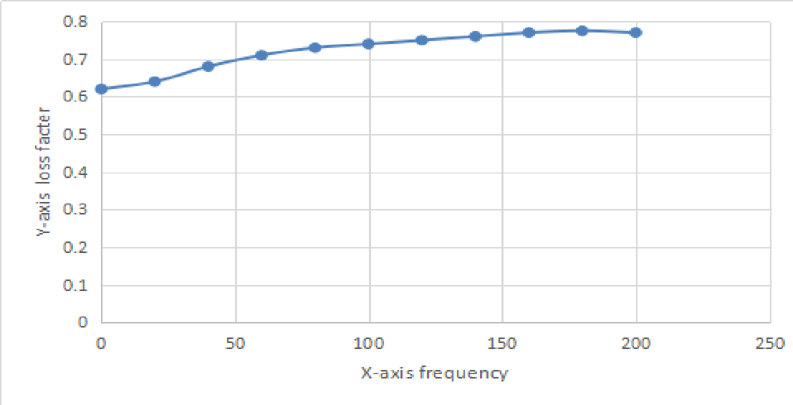


Figure 2-4 the relationship between Dy - 1 damping material loss factor with the frequency (temperature 25 degrees)

The normal temperature of car interior is 25 degrees.We choose damping materials that loss factor η is bigger in temperature 25 degrees From the experimental results, Dy - 1 material compared to the original car damping at 25 degrees of damping loss factor η is bigger.And when the temperature be fixed, in a certain frequency range, the loss factor as the frequency increases, and Dy - 1 is larger than the original vehicle damping material loss factor η, so the choice material Dy - 1 as automotive damping material will be better.

Ⅲ Topology optimization of body floor damping materials

Topology optimization is given the design of the space, to meet certain design load and boundary conditions such as material distribution of the results meet the requirements of the performance goal as constraint, to find the optimal distribution of material of a kind of mathematical optimization method.Using the topology optimization design can satisfy the design requirements of one of the best concept design.Topology optimization design by using the finite element method is analyzed, and combined with relevant optimization technique.

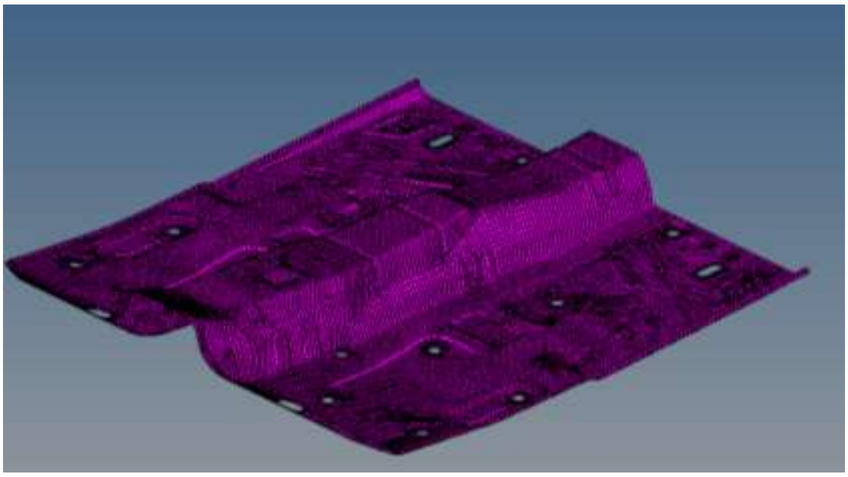


Figure 3-1 body finite element model of the floor

This article is based on the density of damping materials as design variables, with the mass fraction of 20%, 40% and 60% as the constraint condition, with 10 order modal expressions as the objective function for topology optimization.Complex modal characterization real express damping decrement ,imaginary part is modal frequency.

Assuming that real component with α said, imaginary part with β said.The frequency $f = \beta / 2\pi$ and damping factor $\eta = -2\alpha / \beta$.

Table 3-1 The results of body floor complex modal analysis

Modal order	Modal frequency	Real α	Damping factor η
7	4.12	-6.35	4.902405E-02
8	4.200	-5.20	3.934370E-02
9	8.180	-1.08	4.186656E-02
10	12.30	-1.99	5.142980E-02
11	15.70	-2.29	4.606736E-02
12	20.20	-2.74	4.297242E-02
13	21.24	-2.81	4.211285E-02
14	25.47	-3.39	4.232528E-02
15	26.45	-3.65	4.389297E-02
16	34.56	-4.97	4.578080E-02
17	36.39	-4.93	4.311436E-02
18	39.99	-5.32	4.236194E-02
19	41.00	-5.66	4.389887E-02
20	49.03	-7.87	5.109985E-02

The optimization results are as follows:

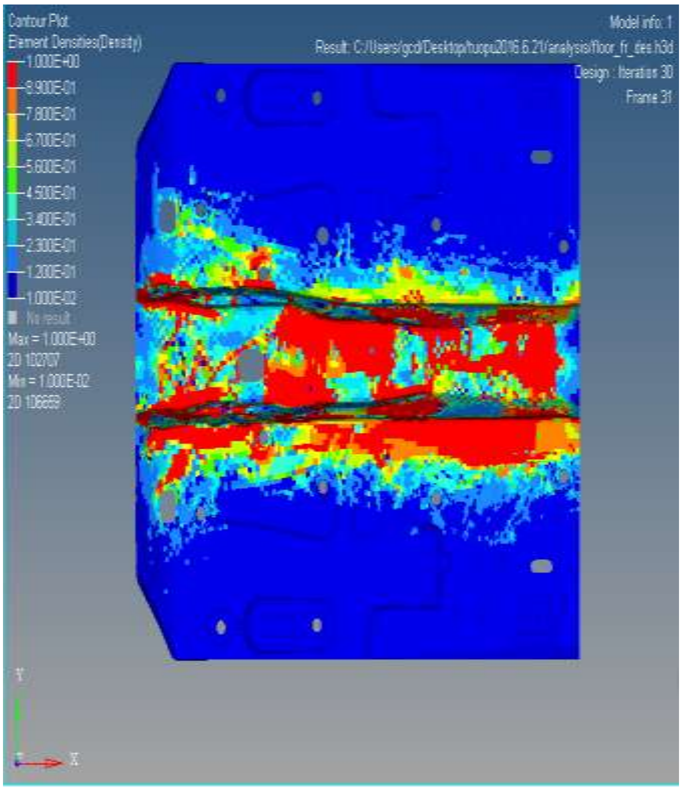


Figure 3-1 body floor damping layer 20% mass fraction constraint results

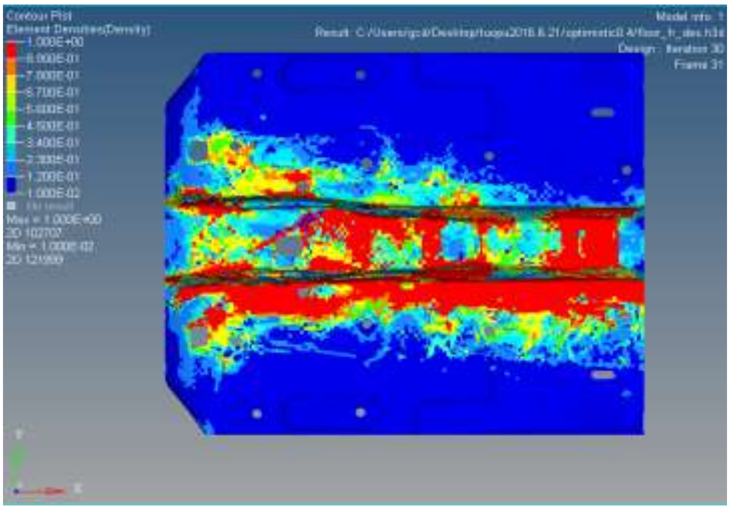


Figure 3-2 body floor damping layer 40% mass fraction constraint results

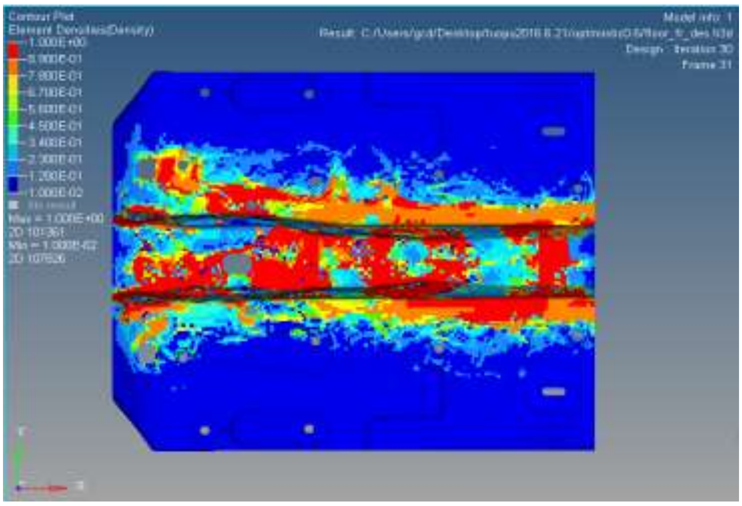


Figure 3-3 body floor damping layer 60% mass fraction constraint results

Table 3-2 different mass fraction of optimized damping factor

	Before optimization	20% mass fraction	40% mass fraction	60% mass fraction
Damping factor η	5.142E-02	6.625E-02	8.223E-02	1.423E-01

Ⅳ.Conclusion

On the damping material selection, we mainly consider that damping materials damping factor change with the temperature and frequency.Considering the temperature inside the generally at room temperature, so we choose bigger damping factor of the material at 25 degrees.At the same time, we also consider damping material damping factor change with frequency, the relationship between general damping material damping factor increases with increased frequency.So in our main consideration when selecting damping materials is the influence of temperature, at a certain temperature range of damping factor is bigger, in under the condition of temperature determined, damping factor and with the increase of the frequency range is not big.

Topology optimization optimize the floor damping materials, mainly in the damping materials with less to get maximum damping factor, seen from the results with the increase of mass fraction damping materials, damping factor is increasing.If we need to get a larger damping factor damping material thickness can be considered .

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