Research on sound transmission characteristics of backing material for ultrasound transducers

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ABSTRACT

Based on acoustical designing demand of backing material for ultrasound transducer, the multiple scattering (MS) theory has been studied for different layered medium. The acoustical transmission characteristics of the periodic structure in ultrasonic frequency band have been given as well. In order to increase acoustic impedance to match the active materials and improve the absorption performance at the same time, it's a good way to fill tungsten powder in epoxy resin and other viscoelastic materials. The test results show that these composites behave good acoustical and material performance. The new absorbing backing materials make ultrasound transducer have good bandwidth and high sensitivity.

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1. INTRODUCTION

The lossy backing is used to absorb the ultrasonic energy of piezocomposite transducers. In order to obtain shorter pulse at the expense of sensitivity, the acoustic impedance of the backing demands to match to the active materials. To achieve greater acoustic impedance, we may select to fill metallic particles in the viscoelastic materials[1].The absorption performance can greatly improved for energy dissipation for viscoelastic materials such as epoxy resin and rubber. The multiple scattering of metallic particles in viscoelastic materials can increase number of propagation routes and improve energy dissipation at the same time.

It is known that the MS method can be used to analyze reflection, transmission and absorption performance. The periodic structure for the spherical[2,3] and axisymmetric cavities[4] were investigated, and the results indicate that the acoustic energy dissipation depends on MS effect. In this paper, we used the MS method to analyze transmission performance of viscoelastic materials containing periodic metallic particles such as tungsten powder for the backing of piezocomposite transducers. The computational results indicate that the metallic particles scattering and base material loss are very important for the sound transmission of backing material.

This year we complete sound absorption model of the MS method for the high precision probe, especially for the scattering particles such as tungsten powder in viscoelastic materials such as epoxy resin. The original model is assumed that scattering metal particle impedance is absolute hard relative base material[5]. The scattering matrix of spherical structure can be used to input accurate material parameters, such as tungsten, nickel or other scattering particles. The sound transmission and absorption properties can be accurately simulated by computing various probe backing.

2. Theory

Every particle center can be seen as the origin of the coordinate system. In spherical coordinate system, the solution can be decomposed into one longitudinal and two transverse solutions[2]:

$$\boldsymbol{u}(\boldsymbol{r}) = \sum_{lm\sigma} [a_{lm}^{\sigma} J_{lm\sigma}(\boldsymbol{r}) + b_{lm}^{\sigma} H_{lm\sigma}(\boldsymbol{r})] \tag{1}$$

For solid medium, $\sigma = L$ denotes longitudinal mode, $\sigma = M, N$ denote SH and SV transverse modes, respectively. a_{lm}^{σ}, b_{lm}^{σ} are the expansion coefficients for the incident and scattered waves,

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respectively. $J_{lm\sigma}(r), H_{lm\sigma}(r)$ are the combined spherical Bessel function and spherical Hankel function where the subscripts are the function orders[3].

The displacement of scattered waves are given by

$$\sum_{l'm'\sigma'}[\boldsymbol{I}_{ll'}\boldsymbol{I}_{mm'}\boldsymbol{I}_{\sigma\sigma'} - \sum_{l''m''\sigma''}\boldsymbol{T}^{\sigma\sigma''}_{lm;l''m''}\boldsymbol{\Omega}^{\sigma''\sigma'}_{l''m'';l'm'}]\boldsymbol{B}^{\sigma'}_{l'm'} = \sum_{l'm'\sigma'}\boldsymbol{T}^{\sigma\sigma'}_{lm;l'm'}\boldsymbol{A}^{O\sigma'}_{l'm'} \tag{2}$$

where $\boldsymbol{I}$ is the unit matrix, $\boldsymbol{A}=[a^{\sigma}_{lm}]$, $\boldsymbol{B}=[b^{\sigma}_{lm}]$. $\boldsymbol{T}$ matrix of equation can describe the relation between the incident waves and scattered waves, both depend on the geometry of the cavity. $\boldsymbol{\Omega}$ describes the scattering effect between the total scattered waves and the sum of the waves from all the other cavities, which in turn depends on the lattice geometry, frequency and the material properties[6].

The transmission coefficient TR is the acoustic energy ratio of the transmission waves to the incident waves, and the transmission loss as follows

$$\mathrm{TL} = 20[\log(\mathrm{TR}) - \log\frac{(\rho c+\rho_w c_w)^2}{4\rho c \rho_w c_w}] \tag{3}$$

Where the transmission coefficient is obtained by multiple scattering method and ρ and c are backing material density and sound velocity, ρ_w and c_w are water medium (or other acoustic wave incident or transmission medium) density and sound velocity.

3. Results and discussions

The transmission loss of viscoelastic materials containing tungsten powder in water are calculated by MS method and the transfer matrix in ultrasonic frequency. If material parameters are not marked for the transmission loss calculation of each graph, the base viscoelastic material density is 1100kg/m^3, Young's modulus is 140MPa and the loss factor is 0.1, Poisson than is 0.49, longitudinal wave velocity is 1481m/s and shear wave velocity is 207m/s. For the material uniformly distributed spherical particles of metal particles, we assume that each unit comprises a tungsten metal (or nickel, steel) particle in cube lattice, where lattice length is 3 micron, sample thickness is 1cm. When tungsten powder particle diameter is 2.5 microns, the volume content of tungsten powder is 30%.

From figure 1 to figure 5 of the calculation results show:

(1) Increasing the thickness of the backing and the loss factor of the base material can effectively improve the acoustic performance of the backing;

(2) The Young's modulus of the base material is related to the acoustic impedance of the backing material. Due to the difference between the base material and the incident medium in impedance, the scattering characteristics of different metal particles are also different, so the sound transmission loss of the backing material is affected.

(3) In a certain range, the volume content of tungsten powder (corresponding to a certain size of the metal particle radius) is larger, the transmission loss is worse.

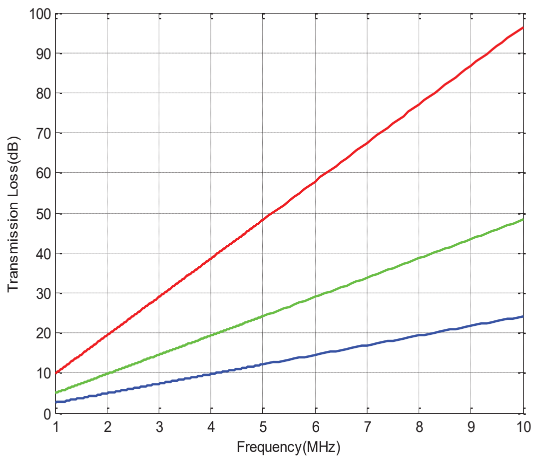

Figure 1 – Transmission loss curves of backing material for different thickness

(red line:1.0cm, green line:0.5cm, blue line:0.25cm)

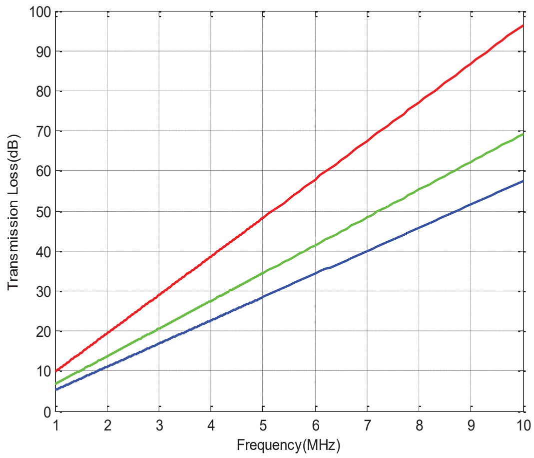

Figure 2 – Transmission loss curves of backing material for different Young's modulus of base material (red line:140MPa, green line:240MPa, blue line:340MPa)

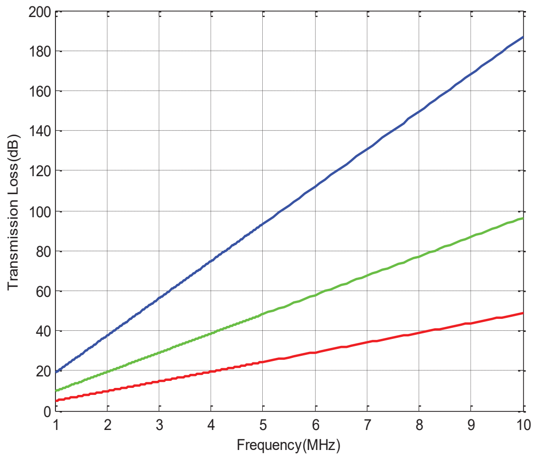

Figure 3 – Transmission loss curves of backing material for different loss factor of base material (red line:0.05, green line:0.1, blue line:0.2)

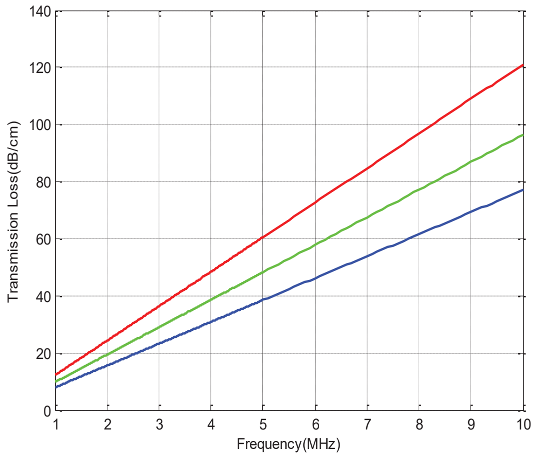

Figure 4 – Transmission loss curves of backing material for different volume content of tungsten powder (red line:20%, green line:30%, blue line:40%)

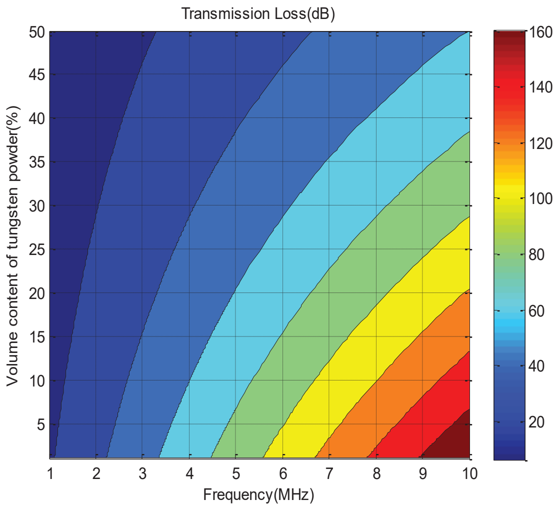

Figure 5 – Transmission loss contour map of volume content of tungsten powder of backing material

Traditional backing materials for epoxy resin and tungsten powder composite structure are commonly poor uniformity for high volume content of tungsten powder. On the other hand increasing with the volume content of tungsten powder, the acoustical performance become worse in a certain range. The preliminary results show that based materials modified research will effectively solve the problem. New base material formulations are comprised epoxy resin, FA resin, curing agent, additives and rubber particles. During the process of mixing with tungsten powder, three roller grinding machine and other equipment can be used to reduce the generation of air bubbles. The test results of new formulations show that the transmission loss will greatly increase. It is seen as figure 6 that we made a series of samples for the new formula. According to Chinese national standard GB/T 18022-2000(the longitudinal wave velocity and attenuation coefficient measurement method in 1-10MHz frequency range for rubber and plastic), the test results are shown in Table 1 at 19.9 ℃ centigrade and at the frequency of 961.5kHz. It can be seen that after the modification of epoxy resin, the acoustic impedance and acoustic transmission attenuation satisfy with the requirements subject for backing materials. In fact the frequency bandwidth test also are more than 110%.

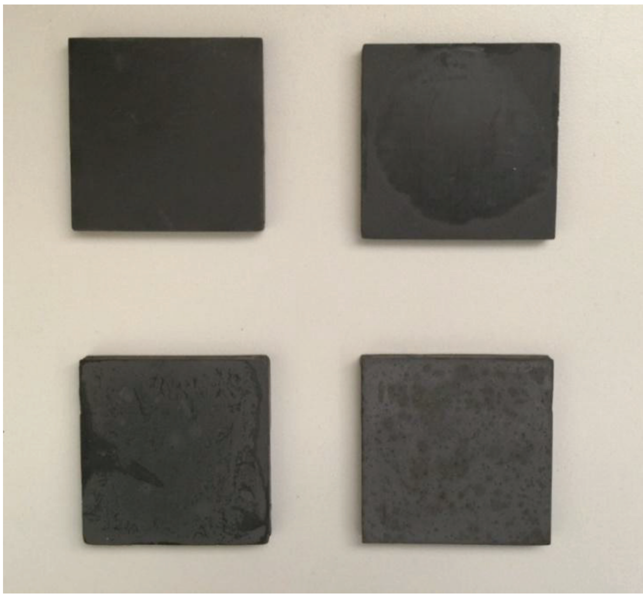

Figure 6 – The new molded samples of epoxy resin composite structure

Table 1 – Test results of a new type of epoxy resin and tungsten powder series

Number	Sound velocity (m/s)	Density (g/cm^3)	Acoustic impedance (MPa·s/m)	Transmission loss (dB/cm)	Transmission loss (dB/cm/MHz)
1	1006	7.76	7.54	51.7	53.77
2	1037	7.98	7.93	45.9	47.74
3	1037	8.3	8.47	45.9	47.74
4	1017	8.48	8.81	55.9	58.14

4. CONCLUSIONS

The basic MS theory on acoustical performance of the viscoelastic materials containing periodic metallic particles is presented in this paper. The material parameters and metallic particle scattering are initially analyzed based on the MS method. The metallic particles in viscoelastic material can improve acoustic impedance and change the transmission performance of the backing. If we need to adjust acoustic impedance to match the active materials and improve the transmission performance at the same time, it’s a good way to adjust volume content of metallic particles and material parameters of viscoelastic materials.

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