CHEMICAL ENGINEERING TRANSACTIONS
VOL. 59, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216
DOI: 10.3303/CET1759113

Research on the Sound Absorption Performance of Metal Rubber Material Based on BP Neural Network

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In this paper, in order to study on the sound absorption performance of metal rubber material, the BP neural network method is used to fulfilling the requirements of data processing. The sound absorption performance of Metal Rubber material was studied theoretically and experimentally. It is feasible to model the sound absorption performance of metal rubber with uniform isotropic porosity. It provides a simple way to study the structural performance of metal rubber accurately. The structure constant is stable for metal rubber material with the same mean cavity diameters. It decreases with increase of the frequency and finally tends to a constant. The frequency factor in the structure constant is varied from 1 to 4/3, while the structure factor decreases in an exponentially decayed way with increase of mean cavity diameter. In the general frequency range, the compressive modules of the sound absorber samples is approximately constant when metal rubber material has the same structure parameters. The ratio of the real part to the imaginary part of the modules increases linearly with increase of mean cavity diameters.

1. Introduction

The control of noise in large powerful fan, internal-combustion engines, gas turbines and jet devices has become more serious with the development of modern technology (Izzheurov, 2009; Dong et al., 2011). It is essential to eliminate or control the noise known as Pipeline Muffler to improve working and living conditions. The study has been focused on the selection of appropriate porous sound- absorption materials, its properties and its mechanism for the practical application. As to sates the requirements of aerospace and national defence weaponry, it is urgent to develop a systematic research on porous sound-absorption material with properties of a wide temperature range, erosion resistance, high intensity, and a long life-span. However, most of currently used sound-absorption materials are not suitable to be used in the severe environment. Porous fibre materials, such as fibre glass and rock, are widely used as sound-absorption materials. Some new porous fibre materials, for instance, metal fibre material, also have been created to satisfy the certain requirement (Duplancic et al., 2017).

In the work of Jiang et al. (2007), the sound-absorption properties of metal fibre materials were studied by using the theoretical formulas to calculate acoustic parameters, but experimental results were not in good agreement with the theoretical values at low frequency. Xi et al. (Xi et al., 2008) developed a physical model to describe the transmission of sound wave in fibber material with assumption of a number of long straight cylindrical fibres with irregular distribution in material. However, the theoretical model is very complex, although it can be used to obtain the effective density and the effective compression modulus. Metal rubber material is a kind of homogeneous porous elastic material. It is manufactured by stacking a specified quantity of tensile spiral wires into a mould and forming through a cold stamping process. Through this technology, metal rubber material has perfect permeability because of connective micro holes and crannies both inside and on the surface of the material. Thus, it can be used as a good sound-absorption material in the severe environment, because it integrates many favourable characteristics, such as high effective porosity (i.e., from 0.13 to 0.95), few dead points, large working surface area, good loading capacity and stability, wide working temperature range, simple manufacturing process, etc. Therefore, it is meaningful to make a systematic research on its acoustic characteristics theoretically and experimentally. Although some sound-absorption parameters and the theoretical calculation of acoustic parameters of metal rubber have been studied (Guo et

Please cite this article as: Yugang Chen, 2017, Research on the sound absorption performance of metal rubber material based on bp neural network, Chemical Engineering Transactions, 59, 673-678 DOI:10.3303/CET1759113

al., 2007), it is still essential to make a systemic study on its sound- absorption performance. In the present study, the formulas of sound absorption parameters of metal rubber material are developed based on an isotropic model. The structure constant for the same mean porosity diameter and the compressive modulus in the general frequency range are studied. The relationship of the sound absorption performance parameter, the frequency and the structure parameters is obtained for the further application of metal rubber in the sound-absorption field.

2. Calculation of acoustic performance parameters of metal rubber

The most important acoustic performance parameters of metal rubber are the sound absorption coefficient, a0, and the acoustic impedance coefficient, ZS. Compared with other porous sound absorption materials, metal rubber has the same performance on sound absorption. Its sound absorption coefficient increases with the increase of the frequency before it reaches the primo resonance sound absorption frequency, f_T. Then, it varies in a certain range. The structure parameters determining the sound absorption performance of metal rubber involve the porosity, o, the metal wire diameter, d, and the thickness of the specimen, h. The micro porosities and crannies inside metal rubber material interconnect to each other in an irregular and isotropic way, which makes the fluid infiltrate equally in any direction. Though metal rubber material is porous, the wires inside are still rigid and non-compressed. In the study, only the movement of fluid inside material is considered. Therefore, the acoustic performance parameters, i.e., the characteristic impedance, ZT, and the propagation constant, it can be calculated as follows (Jiang et al., 2008):

$$\hat{F} = \hat{W}^T \Phi(\mu) \tag{1}$$

It's provided by the adaptive weight law. So estimation error of the weight is

$$\tilde{W} = W - \hat{W} \tag{2}$$

The positive values Wmax as follows:

$$\|W\|_F \leq W_{\max} \tag{3}$$

The adaptive weights law is defined as

$$\dot{\hat{W}} = -kG\|z_2\|\hat{W} - z_2{}^T G\Phi(\mu) \tag{4}$$

$$\varphi_{ji}(\mu_j) = \exp\left(\frac{-\left(\mu_j - C_{ji}\right)^2}{b_{ji}{}^2}\right), \text{for } i = 1, 2, \ldots, H \tag{5}$$

In this space, the mth multidimensional receptive-field function is defined as

$$\Phi_m(\mu) = \prod_{j=1}^{L} \varphi_{ji}(\mu_j), \text{for } m = 1, 2, \ldots, N \tag{6}$$

The function can be written in a vector notation as

$$\Phi(\mu, C, b) = [\Phi_1, \Phi_m \ldots, \Phi_N]^T \tag{7}$$

The weight memory space with N components can be expressed in a vector as

$$W = [W_1, W_m, \ldots, W_N]^T \tag{8}$$

where x is the structural constant of the material, p_o is the density of the air, k is the compressibility modulus of the material, W is the viscosity of the air, and w is the angular frequency. Eqs. (1) and (2) describe the relationship between the acoustic and the structure performance parameters of metal rubber material, respectively. It is noted that x and k are dependent on the frequency and structural parameters of metal rubber material, both of which can be obtained experimentally. When metal rubber is fixed on the rigid wall, its surface acoustic impedance coefficient, Zs, can be deduced as

$$y = W^T \Phi(\mu) \tag{9}$$

From Eq. (3), the sound absorption coefficient, it can be calculated as

$$z_1 = x_1 - y_d \tag{10}$$

$$z_2 = x_2 - \alpha_1 \tag{11}$$

The following tracking error dynamics is shown as:

$$\dot{z}_1 = \dot{x}_1 - \dot{y}_d = x_2 - \dot{y}_d = z_2 + \alpha_1 - \dot{y}_d \tag{12}$$

From (2) and (6), it can be obtained:

$$\dot{z}_2 = \dot{x}_2 - \dot{\alpha}_1 = -M^{-1}Cx_2 - M^{-1}(G_g + d) + M^{-1}\tau - \dot{\alpha}_1 \tag{13}$$

τ is selected as

$$\tau = -\lambda_2 z_2 - z_1 - F \tag{14}$$

Then we can get:

$$V_2 = V_1 + \frac{1}{2} z_2{}^T M z_2 \tag{15}$$

where porn is characteristic impedance of the air. parameters into Eqs. (1), (2), (3) and (4) gives the sound absorption coefficient, ao. Substituting the structure performance acoustic impedance coefficient, Zs, and 3 Determination of structure constant and compressibility modulus As discussed above, the structure constant and compressibility modulus of the metal rubber material are independent on the sound absorption performance parameters. They showed dependency on the frequency and structure performance parameters, i.e., the porosity and the diameter of metal wires, d. In order to study their dependency, a parameter named mean cavity diameter, defined as the da and ad (1)-(5) is introduced into the study. This parameter indicates the average size of the interior cavities. Eq. (5) shows the relationship among the porosity, the metal wire diameter and the mean cavity size inside the material as well.

2.1 Determination of the material structure constant

According to the theoretical calculation formulas of acoustic performance parameter of metal rubber material, the structural constant, x, is of much concern in the research. It also has a very close relationship with the material structure. Actually, it is a key factor for correction between the theoretical and experimental values. It is evaluated as where Zs and it can be measured by standing wave tube measuring method. Thus, the structural constant can be calculated by using of these two parameters.

In the measurement of structural constant, the mean cavity diameters of metal rubber specimen, da, axe with 0.42 mm and 0.21 mm, respectively. There are four types of specimen: o=0.81, d=0.1 mm; Q=0.68, d=0.2 mm; W=0.68, d=0.1 mm; a=0.59, d=0.15 mm. With the consideration of the resonance occurred at the high frequency, the feasible measuring range of frequency is taken from 200 Hz to 2000 Hz. Fig. 1 shows the test results. It is shown from Fig. 1 that the structural constant with the same mean cavity diameter has a good consistency. It means that when the specimen has the same mean cavity diameter, the structural constant of metal rubber is the same. When the mean cavity diameter varies, the structure constant will decrease with the increase of the frequency and finally to a fixed value. Thereby, the structural constant of metal rubber can be described as X=X1-X8, C8 where Xi, is the frequency factor which is related to the angular frequency; Xe is the structure factor dependent on the structure performance of the material. The frequency factor decreases with increase of the angular frequency initially, and then goes to a constant between 1 and 4/3. The structure constant has little effect on low frequency absorption. Furthermore, the frequency factor functions mainly at the range of low frequency, so let it equal to 1. When metal rubber works at high frequency, the structure factor, Xe, approximates to the measured value, which is fitted to obtain its relation with mean cavity diameter, shown in Fig. 2. It is noted that the ratio of the mean cavity diameter, da, and the reference diameter, da, represents the relative mean cavity diameter. In the current case, da=1.0 mm. Fig. 2 shows that the structure factor of metal rubber material decreases with increase of the mean cavity diameter, following an exponentially decayed trend as Eq. (10) is the empirical formula to calculate the structure factor of metal rubber. It indicates that the relationship among structure factor, frequency and structure parameters.

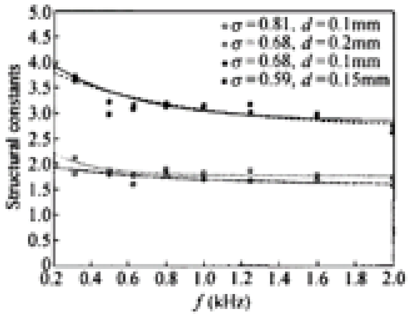

Figure 1: Structural constants with mean cavity diameter da=0.42 mm and 0.21 mm, respectively

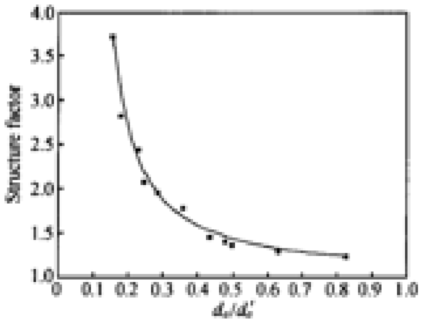

Figure 2: Structure factor vs. relative mean cavity diameter

2.2 Determination of the compressibility modulus

Compressibility modulus, k, obtained experimentally, depicts the expansion and the compression performance of the air in porous materials. It is expressed with a complex format as Lz which shows the compressibility modulus of metal impedance and the propagation constant of metal risibility modulus for different structure factors Po is the balance pressure of the air. Rubber is determined by the characteristic rubber. The experimental results of comparing, in which kT=Po. The frequency has little effect on the compressibility modules at the testing frequency range (200-2000 Hz) because the modules are close to a constant if structure factors are the same. With consideration of practical application of metal rubber material, its acoustic Reynolds number, (da) is usually greater than 1. In the experiment, the real part of relative compressibility modules k/kT varies from 1.2 to 1.4. Thus, the compressibility modules can be expressed ashes k=kT where k' is the compressibility modules of tube (or slot) according to Kirchhoff Theory. The ratio of the real part to the imaginary part of compressibility modules of the material is the same as that of tube (or slot). Assuming that compressibility modules for different structure factors is a constant and neglecting the effect of the frequency, the ratio of the real part to imaginary part of compressibility modules can be described as a function of the mean cavity diameter, expresses as:

$$\dot{V}_2 = -\lambda_1 z_1^T z_1 - \lambda_2 z_2^T z_2 + z_2^T (f - F) - z_2^T (G_g + d) \quad (16)$$

The ideal weight W from (10) and expressed as

$$F = W^T \Phi(\mu) \quad (17)$$

Fig. 3 shows the experimental results of the ratio of the real part to the compressibility modules vs. the relative mean cavity diameters. It can make comparison of the linearly fitting results with the experimental results that point is less than 20%.

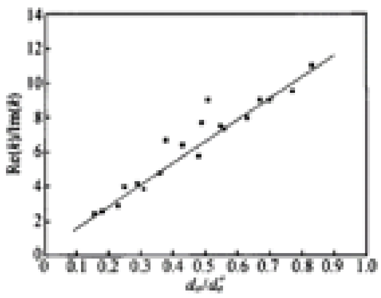

Figure 3: The ratio of the real part to the imaginary part of modulus vs. relative mean cavity diameters

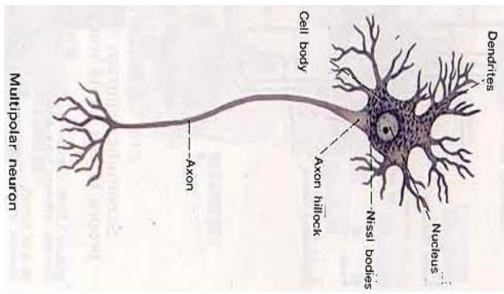

Figure 4: The Structure of Neurons

3. BP neural network model and algorithm

Neural network model originates in neurobiology. In neural networks, many different neurons axon terminals can enter a single neuron dendrite and the formation of synapses (Tang et al., 2008). All of the different sources of synaptic release of neurotransmitter can change the membrane potential of neurons to produce the same effect. It can be seen that the dendrite of neurons in the input information from different sources can be integrated. Figure symbol description is shown in Table 1 (Huang et al., 2014).

Table 1: Mathematical models symbol description

Symbol	Description significance
$x_1, x_2, \dots, x_n$	Enter part of neurons (send information on the first level)
θ_i	Threshold of neurons
y_i	Output neuron
$f[u_1]$	Excitation function

$$u_i = \sum_j w_{ij} x_i - \theta_i \tag{18}$$

$$y_i = f[u_i] = f\left(\sum_j w_{ij} - \theta_i\right) \tag{19}$$

4. Comparison of the theoretical and experimental results of sound absorption performance parameters

Structural constant and compressive modulus is analysed experimentally, and formula of acoustic characteristic parameters as well as sound absorption performance parameter are obtained based on the relationship between structure constant, compressive modulus and material characteristic parameters. The good agreement between the calculated and experimental results of sound absorption coefficient testifies the effectiveness of theoretical method and experimental operation. The mathematical model of sound absorption parameters of MR at resonance were proposed for the application of MR. The calculated results shows good agreement with the experimental ones which indicates that the method to investigate the acoustic parameters at resonance is effective and accurate. Sound absorption performances of single layer and bilayer structures are presented and the calculation formulas of parameters of these structures are deduced based on formula of acoustic characteristic parameters. Effects of material thickness, flow resistivity, and air layer thickness on sound absorption performances of single layer and bilayer structures are investigated by comparing the acoustic absorption performances of single layer and bilayer structures. In the study, four categories of metal rubber samples are tested: Sample 1: Q=0.86, d=0.1 mm, h=20 mm; Sample 2: Q=0.81, d=0.1 mm, h=20 mm; Sample 3:=0.72, d=0.1 mm, h=21 mm; Sample 4: Q=0.62, d=0.1 mm, h=21 mm. Using a standing wave tube measuring method, the sound absorption coefficients of metal rubber are tested. The calculated and experimental results are shown in Fig. 7 and Fig. 8, respectively.

Compared with other porous sound absorption materials, metal rubber has the same performance on sound absorption. Its sound absorption coefficient increases with the increase of the frequency before it reaches the primo resonance sound absorption frequency, fT. Then, it varies in a certain range. The structure parameters determining the sound absorption performance of metal rubber involve the porosity, o, the metal wire diameter, d, and the thickness of the specimen, h. The micro porosities and crannies inside metal rubber material interconnect to each other in an irregular and isotropic way, which makes the fluid infiltrate equally in any direction. Though metal rubber material is porous, the wires inside are still rigid and non-compressed.

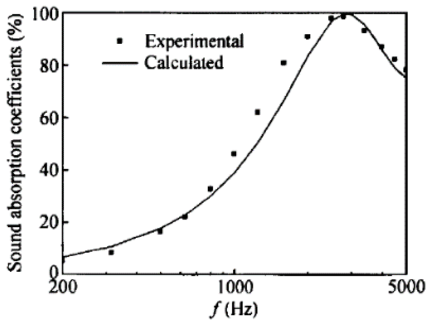

Figure 5: Comparison of the calculated and experimental sound absorption coefficients of sample 3

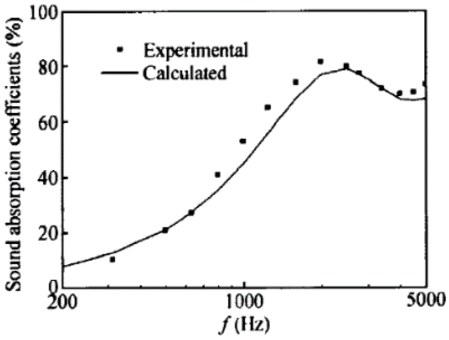

Figure 6: Comparison experimental of the calculated and sound absorption coefficients of sample 4

5. Conclusion

In this paper, in order to study on the sound absorption performance of metal rubber material, the BP neural network method is used to fulfilling the requirements of data processing. The experiment result shows the simulation platform for rubber material sound absorption performance can be improved by using the big data fusion platform. The frequency factor in the structure constant is varied from 1 to 4/3, while the structure factor decreases in an exponentially decayed way with increase of mean cavity diameter. In the general frequency range, the compressive modules of the sound absorber samples are approximately constant when metal rubber material has the same structure parameters. The ratio of the real part to the imaginary part of the modules increases linearly with increase of mean cavity diameters.

Acknowledgments

The authors acknowledge the Humanities and Social Sciences Program of Jiangxi province in 2014 (YS1440) and 2015 Jiangxi social science "12th Five-Year" program (15YS21).

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