SOME RESEARCH ASPECTS OF ACOUSTIC CHARACTERISTICS OF METAL RUBBER PRODUCED WITH NEW TECHNOLOGY

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This article deals with the possibility of applying the material called «metal rubber» (MR) as a sound-absorbing structure. Porous materials have found wide application in reducing noise. However not all materials can be used at high temperatures and MR could be an alternative in these cases. The article describes the acoustic characteristics of MR. The basic acoustic properties of this material which is made by new technology, was investigated. Researches of influence of various design data on metal rubber’s acoustic properties were conducted. The software for an impedance tube has been made using the graphical programming environment Lab View and experimental results have also been obtained. As a result, the analysis dependence between sound absorption coefficient and porosity of the sample, for the products developed by the new technology is reported. A mathematical model for determining the air flow resistivity and the acoustic properties of elastic porous material MR were also developed. Coefficients of a mathematical model to calculate the acoustic characteristics of the MR was selected. The values of resistivity blowing and the sound absorption coefficient dependences on the parameters of the sample were calculated. The analysis established the relationship between sound absorption and flow resistivity and the influence of the thickness of the wire and the sample porosity on these parameters. A comparison of calculated and experimental data was carried out.

1. Introduction

Current technology – and above all, aerospace technology – is characterized by the increased unsteady mechanical, heat and hydrodynamic loadings on assemblies and structure components of products. As this takes place, along with the traditional problems of their development connected with their reliability and maintainability, it is necessary to solve a number of new problems including, above all, competitive costs of product development and high level of environmental security requirements.

To reduce the noise of power stations, it is advantageous to use sound absorbers made of metal rubber (MR) – a homogeneous porous structure obtained by cold pressing of weight-dosed extended wire spiral.
2. **Experimental and theoretical studies of metal rubber**

To reduce the costs of products and to expand the range of wires in terms of their composition and diameter, new samples have been developed for which, instead of the spiral coiling operation \(^6\), the bead forming operation was introduced (B). To compare the new technology effect on the performance characteristics, samples of the same wire have been made with similar porosity using the conventional technology (C). The characteristics of the tested samples are shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Conventional MR manufacturing method (C)</th>
<th>Beading-based MR manufacturing method (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(\sigma = 0.810) (dw = 0.2) (h = 6.3) mm</td>
<td>(\sigma = 0.605) (dw = 0.2) (h = 5.4) mm</td>
</tr>
<tr>
<td>2</td>
<td>(\sigma = 0.698) (dw = 0.2) (h = 5.4) mm</td>
<td>(\sigma = 0.699) (dw = 0.2) (h = 5.45) mm</td>
</tr>
<tr>
<td>3</td>
<td>(\sigma = 0.803) (dw = 0.2) (h = 6.6) mm</td>
<td>(\sigma = 0.629) (dw = 0.2) (h = 6.2) mm</td>
</tr>
<tr>
<td>4</td>
<td>(\sigma = 0.686) (dw = 0.2) (h = 5.2) mm</td>
<td>(\sigma = 0.807) (dw = 0.2) (h = 5.1) mm</td>
</tr>
<tr>
<td>5</td>
<td>(\sigma = 0.689) (dw = 0.2) (h = 5.1) mm</td>
<td>(\sigma = 0.818) (dw = 0.2) (h = 5.5) mm</td>
</tr>
<tr>
<td>6</td>
<td>(\sigma = 0.589) (dw = 0.2) (h = 5.2) mm</td>
<td>(\sigma = 0.7) (dw = 0.2) (h = 5.45) mm</td>
</tr>
<tr>
<td>7</td>
<td>(\sigma = 0.605) (dw = 0.2) (h = 5.3) mm</td>
<td>(\sigma = 0.797) (dw = 0.2) (h = 5.4) mm</td>
</tr>
<tr>
<td>8</td>
<td>(\sigma = 0.809) (dw = 0.2) (h = 6.6) mm</td>
<td>(\sigma = 0.722) (dw = 0.2) (h = 3.8) mm</td>
</tr>
<tr>
<td>9</td>
<td>(\sigma = 0.601) (dw = 0.2) (h = 5.3) mm</td>
<td>(\sigma = 0.818+797+807) (dw = 0.2) (h = 5.5+5.4+5.1) mm</td>
</tr>
<tr>
<td>10</td>
<td>(\sigma = 0.8) (dw = 0.2) (h = 5) mm</td>
<td>(\sigma = 797+807) (dw = 0.2) (h = 5.4+5.1) mm</td>
</tr>
<tr>
<td>11</td>
<td>(\sigma = 0.8) (dw = 0.2) (h = 5+10) mm</td>
<td>(\sigma = 807) (dw = 0.2) (h = 5.1) mm</td>
</tr>
<tr>
<td>12</td>
<td>(\sigma = 0.8) (dw = 0.12) (h = 10) mm</td>
<td>(\sigma = 0.7+0.698+0.722+0.699) (dw = 0.2) (h = 5.45+5.4+3.8+5.45) mm</td>
</tr>
<tr>
<td>13</td>
<td>(\sigma = 0.8) (dw = 0.15) (h = 10) mm</td>
<td>(\sigma = 0.698+0.722+0.699) (dw = 0.2) (h = 5.4+3.8+5.45) mm</td>
</tr>
<tr>
<td>14</td>
<td>(\sigma = 0.8) (dw = 0.2) (h = 10+10) mm</td>
<td>(\sigma = 0.722+0.699) (dw = 0.2) (h = 3.8+5.45) mm</td>
</tr>
<tr>
<td>15</td>
<td>(\sigma = 0.8) (dw = 0.2) (h = 10+10+5) mm</td>
<td>(\sigma = 0.699) (dw = 0.2) (h = 5.45) mm</td>
</tr>
<tr>
<td>16</td>
<td>(\sigma = 0.7) (dw = 0.2) (h = 10) mm</td>
<td>(\sigma = 0.627+0.629+0.605) (dw = 0.2) (h = 6.2+6.2+5.4) mm</td>
</tr>
<tr>
<td>17</td>
<td>(\sigma = 0.7) (dw = 0.12) (h = 10) mm</td>
<td>(\sigma = 0.629+0.605) (dw = 0.2) (h = 6.2+5.4) mm</td>
</tr>
<tr>
<td>18</td>
<td>(\sigma = 0.6) (dw = 0.12) (h = 10) mm</td>
<td>(\sigma = 0.605) (dw = 0.2) (h = 5.4) mm</td>
</tr>
</tbody>
</table>

Where \(\sigma\) – porosity, \(dw\) – wire diameter, \(h\) – sample thickness
To develop software for measuring the acoustic properties of sound absorbing materials, the following equipment was used:

- Impedance tube by Spectronics;
- NI USB-4431 Data acquisition;
- PCB 377B02 Microphones.

For generating broadband noise and the microphones signal processing NI USB – 4431 Data acquisition was used.

For automated measurement process, unique software was developed based on Lab VIEW development environment (‘Sound and Vibration’ Application). The appearance of the testing equipment is shown in Fig. 1.

The reiteration test was carried out to explore the acoustic properties of MR samples according to the new technology with the same wire diameter, sample thickness and porosity (Fig. 2a). They demonstrated a good sound absorption coefficient convergence. Fig. 2b suggests that the main acoustic properties of MR produced by new technology repeat the properties of the samples produced by conventional technology. This testifies the possibility to use the experience of measurement and estimation of the acoustic properties of MR made by conventional technology to describe the acoustic properties of MR made by new technology.
Apart from the experimental data, it is necessary to forecast the structure acoustic characteristics at the stage of its designing. The mathematical model describing the acoustic characteristics of the elastoporous MR material (the coefficient of sound absorption at normal incidence) based on well-known Delany-Bazley's formulas may be written as:

\[ \alpha = 1 - \left( \frac{Z_{in} - Z_0}{Z_0 + Z_{in}} \right) \]

\[ Z_{in} = Z_c \cdot \coth(\gamma \cdot l) \]

\[ \gamma = \left( j \frac{\omega}{c_0} \right) \left[ l + C_1 \cdot B^{-C_2} - j \cdot C_3 \cdot B^{-C_4} \right] \]

\[ Z_c = \rho_0 c_0 \left[ l + C_5 \cdot B^{-C_6} - j \cdot C_7 \cdot B^{-C_8} \right] \]

where
- \( Z_{IN} \) – input impedance
- \( l \) – sample thickness
- \( \gamma \) - propagation constant,
- \( Z_c \) - acoustic impedance,
- \( B = \frac{\rho_0 f}{r} \)
- \( B \) – non dimensional frequency dependent variable
- \( \rho_0 \) medium density,
- \( f \) – frequency,
- \( c_0 \) – sound speed in air,
- \( r \) - airflow resistivity,
- \( C_1...C_8 \) – material-dependent experimental coefficients

To determine coefficients \( C_1...C_8 \) experimental data obtained during impedance tube measurements were used. The obtained model was optimised at 36 MR samples. The determined coefficients are shown in Table 2.

<table>
<thead>
<tr>
<th>MR</th>
<th>( C_1 )</th>
<th>( C_2 )</th>
<th>( C_3 )</th>
<th>( C_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated coefficients</td>
<td>0.057</td>
<td>0.754</td>
<td>0.087</td>
<td>0.732</td>
</tr>
<tr>
<td></td>
<td>( C_5 )</td>
<td>( C_6 )</td>
<td>( C_7 )</td>
<td>( C_8 )</td>
</tr>
<tr>
<td></td>
<td>0.169</td>
<td>0.595</td>
<td>0.098</td>
<td>0.700</td>
</tr>
</tbody>
</table>

To measure the performance of sound absorption materials the airflow resistivity unit \( r \) is used, which is determined as the ratio of the pressure drop per length unit of the porous element to the volume velocity of gas \( q_v \), flowing through the element.

\[ r = \frac{\Delta p \cdot A}{l \cdot q_v} \]

where \( \Delta p \) - is the pressure drop at the porous layer; \( q_v \) – volume velocity of the air flow.

Table 3 shows the values of the airflow resistivity measured by the acoustic method and the one measured in the constant flow.

| Table 3. Airflow resistivity values |

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There are two main empirical mathematical models to determine the airflow resistivity of the porous material:

1. Bies-Hansen method

\[
r = \frac{K_2}{d_w^3 \cdot \rho_m^2 \cdot K_1}
\]

2. E.A.Izzheurov's method

\[
r = \frac{A \cdot (1 - \sigma)^2}{2 \cdot \sigma^3 \cdot d_w^2 \cdot \eta}
\]

\(d_w\) – fibre diameter;

\[d_H = \frac{\sigma \cdot d_w}{(1 - \sigma)}\]

\(d_H\) – hydraulic diameter of the porous medium

\(\rho_m\) – apparent density (kg/m³);

\[\rho_m = (1 - \sigma) \cdot \rho\]

\(\sigma\) – sample porosity;

\(\rho\) – wire density;

\(\eta\) – viscosity index;

A=153 - experimental coefficient for MR;

\(K_1, K_2\) – material dependent experimental coefficients.

Knowing the airflow resistivity parameters measured for several samples (Table 3) made of MR, the following coefficients were selected \(K_1, K_2\).
Figure 3 – Comparison of estimated and experimental dependencies of airflow resistivity of the MR hydraulic diameter

Table 4. Experimental coefficients for $K_1, K_2$ of Bies-Hansen model

<table>
<thead>
<tr>
<th>Material</th>
<th>$K_1$</th>
<th>$K_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR (determined coefficients)</td>
<td>2.985</td>
<td>$4.8 \cdot 10^{-14}$</td>
</tr>
<tr>
<td>Glass fibre</td>
<td>1.53</td>
<td>$3.8 \cdot 10^{-9}$</td>
</tr>
</tbody>
</table>

The graph shown in Fig. 3 allows to make the following conclusions:
1. The estimated data obtained by Bies-Hansen and E.A. Izzheurov methods agree well with the experimental values;
2. For sufficient convergence of the estimated data obtained by Bies-Hansen method, it is necessary to select new coefficients $K_1, K_2$.

In such a manner various methods of estimating airflow resistivity have been studied with further comparison with the experimental data.

From the above dependencies follows the conclusion that the sound absorbing ability of MR porous material depends on the values of several structural parameters (porosity, wire diameter, material thickness, etc.). It is known that by the airflow resistivity of porous material it is possible carry out complex evaluation of its sound absorbing ability taking into account all its structural properties.

The next stage involves comparison of experimental data on MR samples made by means of various technologies. The estimated sound absorption coefficients agree well with the experimental data (Fig. 4).

The refined Delany-Bazley mathematical model allows to calculate the sound absorption coefficients as a function of pour density. This model can provide the acoustic impedance and propagation constant values as well as the sound absorption coefficient depending on the airflow resistivity (in so doing the sample thickness is included into the airflow resistivity formula).
3. Conclusion

The main outcome of this work has been the development, up to a constant, of a mathematical model describing the acoustic characteristics of 'metal rubber' elastoporous material. Dependencies between the sound absorption coefficient and airflow resistivity have been established, as well as the effect of the porosity and thickness of wires and samples on these parameters.

The testing equipment has been updated by means of developing a new information and measurement system. New software for experimental studies has been developed.

REFERENCES