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The investigation of influence of paint coatings on structure vibrations

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Abstract The paper examines the vibration velocity of a circular plate. Layers of paint were applied successively, the weight of the paint coating was measured and the effect of the thickness of the coating layers on the speed and amplitude of structure vibrations were tested. Differences in the vibration speed caused by the presence of the paint coating were noted. With the next layer of varnish, the resonance value of the plate shifts towards higher frequencies.

Keywords: vibration speed, round plate, paint coatings.

1. Introduction

As a result of the operation of machines and aerodynamic phenomena, vibrations arise that destroy machines, cause hearing damage. To prevent this, among other things, varnish coatings are used, which dampen vibrations, change their frequency, thanks to which the threat of resonance and, as a result, the destruction of the structure is reduced [1]. One of the methods of reducing noise is covering plate metal and structural elements with paints, which have the ability to dampen vibrations using appropriate resins and fillers.

One of the methods of reducing noise is covering plate metal and structural elements with paints that, thanks to appropriate resins and fillers, have the ability to dampen vibrations. Filling similar to moisture-absorbing paints, bound with resins with appropriate flexibility, has the ability to damp vibrations and retain a certain amount of moisture [2].

On the other hand, porous boards and plasters are characterized by a high sound absorption coefficient for medium and high frequencies and smaller absorption for low frequencies. The sound absorption of these panels in the low frequency range can be increased by making them plate, perforated or slotted structures. Painting sound-absorbing panels with paint or impregnation may reduce the absorption coefficient in the high-frequency range [3].

In the study conducted by Chrisler there were presented photos and results of sound absorption measurements for many different types of materials before and after painting. Moreover, the article provided brief overview of the types of paints and their usefulness in minimizig the impact on acoustics property [4].

Vibration-damping paints contain materials with vibration-damping properties. These materials may be added to the paint during the manufacturing process, or may be applied as a coating to a painted surface. The most commonly used vibration damping materials are copper, carbon, graphite powder, as well as elastomeric fillers such as rubbers or polymers [5]. These materials are added to paints, because they have the ability to absorb and dissipate vibration energy, leading to a reduction in noise and vibration levels.

Vibration damping paints are mainly used in the automotive, aerospace and marine industries, which is important to minimize noise and vibration. They can also be used in homes and buildings to reduce indoor noise levels. It is important to remember that vibration damping paints do not always completely eliminate noise and vibration, but they can significantly reduce their level.

Evaluation of the effectiveness of vibration damping paint can also be based on the study of its mechanical properties, such as Young's modulus, tensile strength or elasticity. The high flexibility of the paint can also affect its ability to dampen vibrations [6-9].

It is also worth considering, that studies conducted as a part of scientific and industrial projects on vibration damping in various applications, regarding automotive industry, aviation, construction or power industry can provide valuable insights into the effectiveness of vibration-damping paints in practical applications [10, 11].

In addition, there are products on the market offered by companies from the automotive industry presenting technologies that ensure the reduction of sounds caused by mechanical vibrations in cars, trucks, trains or machines. Sound attenuation systems are based on specially selected acrylic resins [12].

2. Measurement setup and instruments

The tested object was a round steel plate with diameter of 240 mm and a thickness of 1 mm. The plate was fixed to the ground with two 3 mm thick steel rings. The dimensions of the steel plate are shown in Fig. 1. The characteristic parameters of the analyzed plate are shown in Table 1. In this table: d_z – plate diameter, x – plate thickness, d_o – hole diameter, w – plate weight, E – is Young's modulus of elasticity, ρ – is the mass density and ν – is the Poisson ratio, respectively.

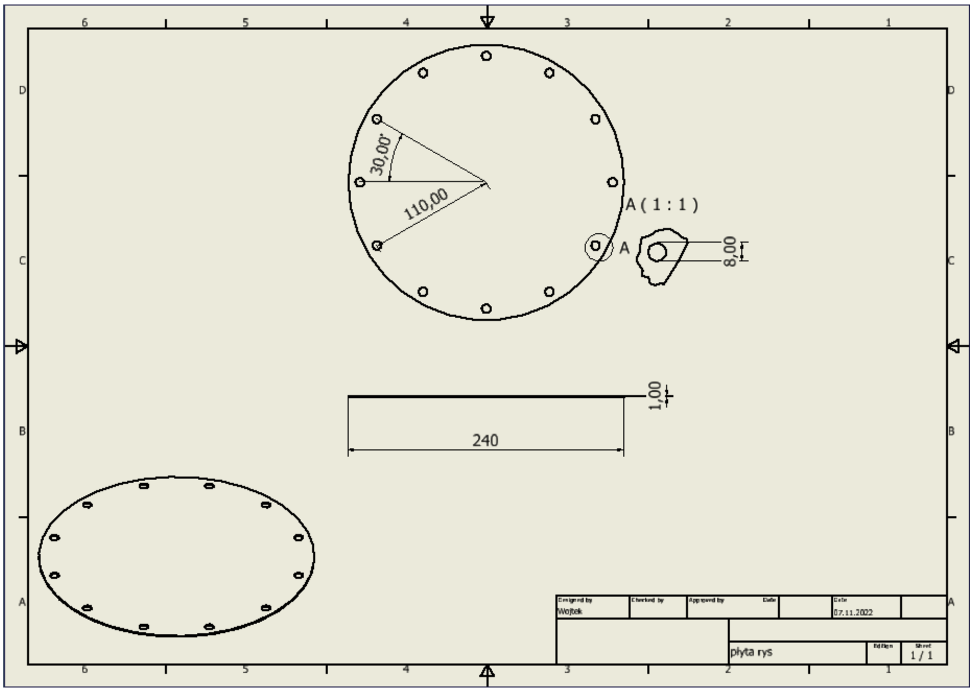

Figure 1. Dimensions of the steel plate.

Table 1. Parameters characterizing the analyzed plates.

Model	d_z [mm]	x [mm]	$d_o \times 12$ [mm]	w [g]	E [GPa]	ρ [g/cm^3]	ν
solid plate	240	1	8 × 12	347.6	210	7.85	0.3
paint				5	2.2	0.0012	0.2

Both in experimental tests and in FEM simulation, the analysis was limited to low frequencies, i.e. from 20 to 500 Hz. This range includes the first natural frequency of the plate ω_{10} relating to the form associated with one nodal circle. Then, a simplified FEM model of the plate was determined, which would reflect its dynamics. Table 2 contains the results of the FEM modal analysis for the plate itself (without the measurement setup).

Table 2. Natural Frequencies ω_{10} [Hz] for the solid plate FEM.

No	Number of paint layers	Paint layer thickness [μm]	Natural frequency ω_{10}	Magnitude [μm]
1	0	0	255	558
2	1	130	256	234
3	2	260	257	132

In order to quantitatively compare the results obtained in this work, the so-called frequency error determined by the relationship [13, 14]:

$$\mathcal{E} = (\omega^{f} - \omega^{e}) / \omega^{e} \cdot 100\% \tag{1}$$

where ω^{f} is the eigenfrequency from the object model and ω^{e} is the eigenfrequency of the real system.

The base was a wooden plate placed above the loudspeaker on four wooden legs attached to the box with the loudspeaker. The construction of the measuring station and the method of mounting the plate are shown in Figure 2.

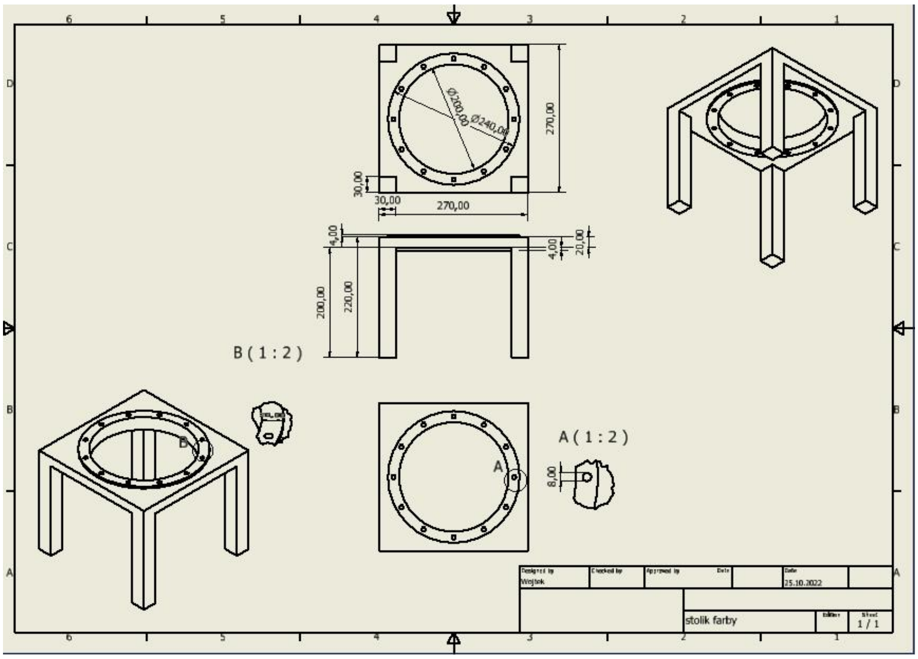

Figure 2. Dimensions of the measuring station.

The plate was mounted with twelve screws to the structure shown in Figure 3. Each screw was tightened with a moment of force of 10 Nm. The source of vibrations was a loudspeaker placed below the structure at a distance of 23 cm from the tested slab. The distance between the slab and the floor of the room was 50 cm. The measuring stand is shown in Figure 3.

Figure 3. Measurement setup.

The velocity and amplitude of the plate vibrations were tested using the Polytec PDV-400 vibrometer. PSV Acquisition and PSV Presentation software were used for data measurements and analysis. The laser was placed 50 cm above the tested plate. Plate vibrations were tested at the specific points of the grid (Fig. 4).

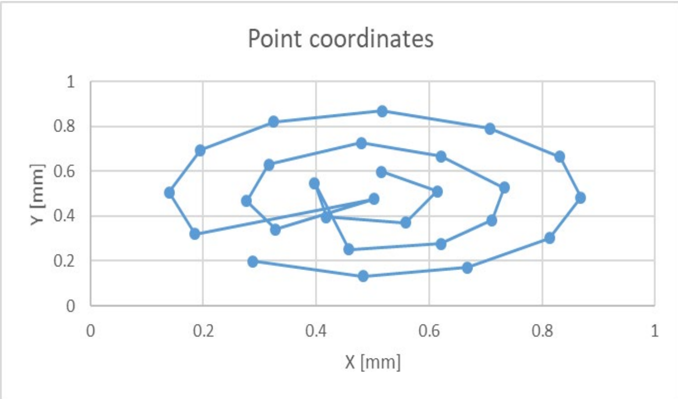

Figure 4. Measuring grid.

The measurements were carried out by generating the Chirp signal with the frequency range from 20 Hz to 500 Hz. Then, the research was continued by generating vibrations with the constant frequency, successively: 211.3 Hz, 216.3 Hz and 222.5 Hz. These values are equal to the frequencies at which the plate resonated during the chirp test - 211.3 for the board alone, 216.3 Hz for the board covered with one layer of paint and 222.5 for two layers.

Measurements were carried out in the following stages:

1. The plates were weighed. Then, the speed and amplitude of vibrations of the plate itself without additional varnish layers were tested (Fig. 3). The tests were carried out generating the Chirp signal and then with the constant excitation frequency of 211.3 Hz.
2. The round plate was covered with the first layer of black anti-corrosion paint for metals. The thickness of the applied coating ranged 130 μm and the weight was 5 grams. The measurement was made by generating the Chirp signal, and then with the constant excitation of 216.3 Hz.
3. In the next step, the round plate was covered with another layer of paint, thus increasing the thickness of the plate by another 130 μm and 5 grams. The weight of the paint was 1% of the weight of the sample. The plate was tested using the Chirp signal. Then at the constant frequency of 222.5 Hz.
4. Analogous tests were performed for a different type of paint with various properties and chemical composition (white polyurethane paint), including plate vibrations measured without additional layers. Secondly, the plate was painted with the first layer of paint (white polyurethane) with a thickness of 130 μm. After the measurements were made, the plate was covered with a second layer of paint.

The next part of the article presents the results of the influence of the varnish coating on the panel response (vibration amplitude and speed).

The first sample was covered with black anti-corrosion paint for metals, while the second one was covered with white polyurethane paint. Experimental results showed that the paint surface can change the dynamic response of the plate.

3. Identification of object parameters

Measurements were made using the PDV-400 laser vibrometer for non-contact measurement in similar way as described in quoted studies [15-18]. This device determines the vibration velocity and displacement of individual points on the surface of the considered object. The surface of the plate was scanned automatically with the use of an interactive and flexible grid of measurement points controlled and configured using the software supplied with the device. In this way, the resonance frequencies were determined. The plot of the frequency response of the object is shown in Figure 5.

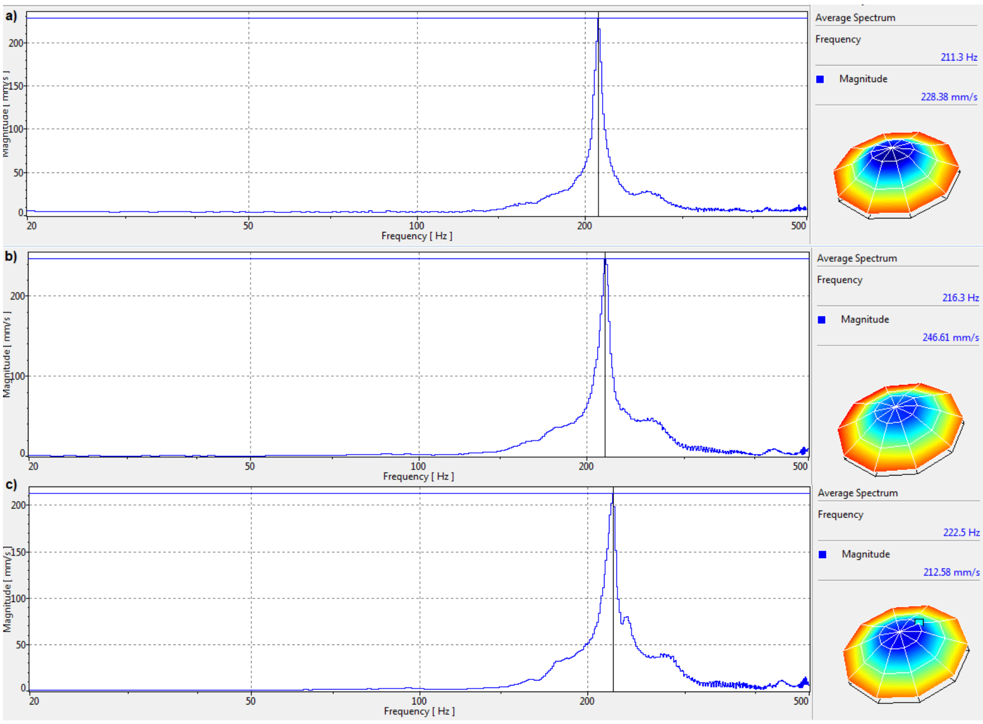

Figure 5. Reaction of the object to the chirp signal: a) plate metal, b) plate metal painted with black anti-corrosion paint (first layer of paint), c) plate metal painted with black anti-corrosion paint (second layer of paint).

The object responded to excitation ranged from 70 Hz to 500 Hz. Stronger response was seen around 150 Hz, up to 210 Hz. There was a clear peak amplitude for the plate without paint at 211.3 Hz. It was noticed that with the application of successive layers of paint, the amplitude of the peaks shifted towards higher frequency values. From 211.3 Hz for the board only, 216.3 Hz for the board covered with the first layer of paint (130 µm) to 216.3 Hz for the board covered with the second layer of paint (paint thickness 260 µm). For this reason, excitation with fixed frequency signals of 211.3 Hz, 216.3 Hz and 222.5 Hz was used for further research. The obtained measurement results are shown in Figure 6.

Figure 6. Differences in board response to the chirp signal in the form of the first and second resonant frequencies for painted and non-painted boards.

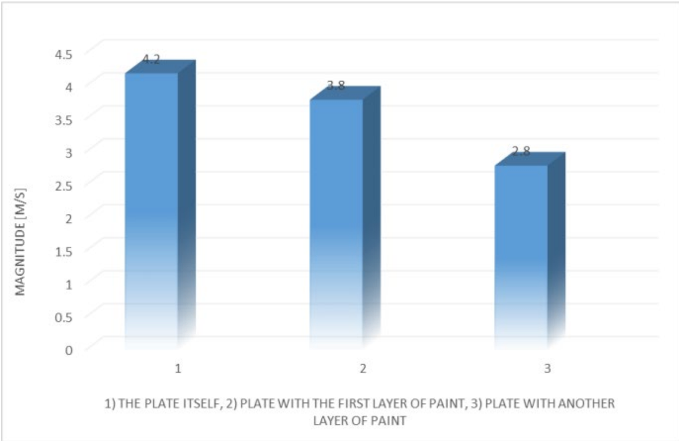

Figure 7. Influence of the paint coating on the vibration speed of the resonant value.

It was noticed that with the application of subsequent layers of paint, the resonant frequency occurred at lower vibration speed. For the plate without paint the resonant frequency appeared at 211 Hz with the speed of 4.2 m/s, for the plate with the first layer of paint ranged 216.3 Hz at a maximum speed of 3.8 m/s and for the plate with the second layer of paint the resonant frequency occurred at 222.5 Hz and speed of 2.8 m/s (Fig. 7).

Below there is a comparative drawing of the response of a plate excited with a frequency of 70 Hz without paint, with one layer of paint and with the second layer of paint (Fig. 8).

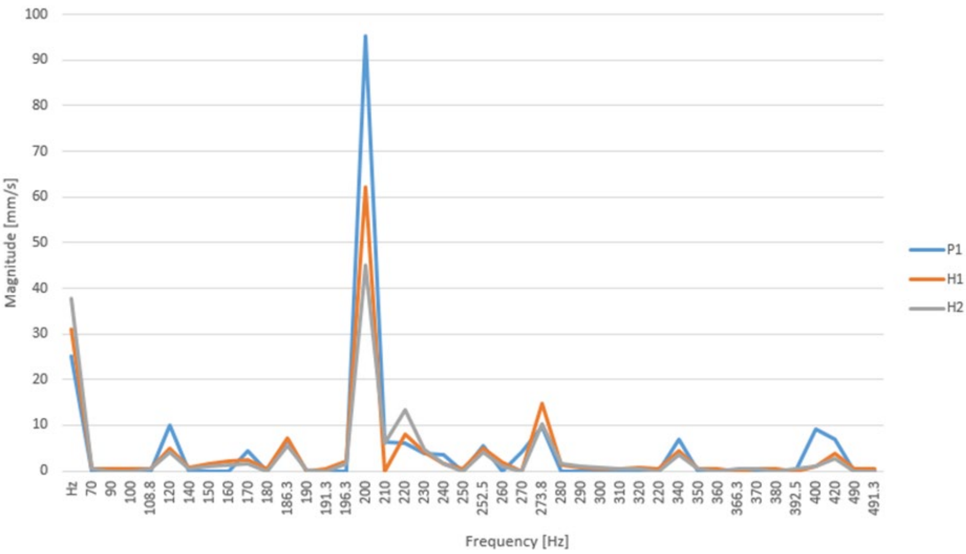

Figure 8. Object response to excitation at the frequency of 70 Hz.

Analyzing the response of the plate at a given constant vibration frequency of 70 Hz, it can be seen (Fig. 8) that with the application of successive layers of paint, the vibration velocities decreased. The value of the resonance amplitude of the plates covered with paint and without paint was also analyzed. A tendency of the resonant amplitude to move with the next layer of paint towards higher frequencies was noticed (Fig. 9). In addition, with the application of successive layers of paint, the value of the resonant amplitude decreased. For the plate without paint, using the chirp signal, the amplitude was 229.75 μm, after applying the first layer of paint it is 136.06 μm, and after applying the second layer of paint it is 132.63 μm.

Additionally, a 3D model of the measurement system and the harmonic response of the plate was made and its modal analysis was carried out using the FEM method, with and without a paint coating. Table 3 shows the parameters characterizing the tested system.

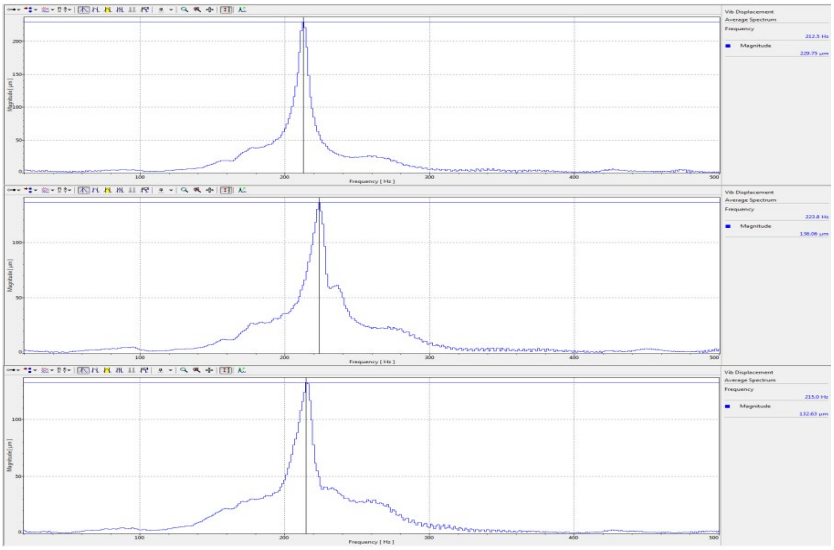

Figure 9. The value of the resonant amplitude for plates covered with paint and without paint.

Table 3. Parameters characterizing the analyzed assembly components.

Model	d_z [mm]	x [mm]	$d_o \times 12$ [mm]	D_{zp}; d_{wp}; w_p [mm]	E [GPa]	ρ [g/cm^3]	ν
plate	240	1	8 × 12	240; 200; 4	210	7.85	0.3
table					22.78	0.93	0.37
paint					2.2	0.0012	0.2

In this table: d_z – plate diameter, x – plate thickness, d_o – hole diameter, d_{zp} – outer diameter of the ring, d_{wp} – inner diameter of the ring, w_p – ring thickness, E – Young's modulus of elasticity, ρ is the mass density and ν is the Poisson ratio, respectively.

Then, a modal FEM analysis of the plate without and with paint coatings was performed. In Table 4 there are results related to executed FEM analysis. Using formula (1), the relative frequency error was calculated for the model of the plate itself and the plate mounted on the measuring setup. The error values are presented in Table 5.

Table 4. Experimental natural frequencies ω (Hz) for the plate fixed in measurement setup in FEM.

No	Number of paint layers	Paint layer thickness [μm]	Natural frequency ω_{10}	Magnitude [μm]
1	0	0	248	210
2	1	130	251	172
3	2	260	252	112

Table 5. Frequency error.

No	Number of paint layers	Plate (FEM), Ɛ %	Plate with measurement setup (FEM), Ɛ %
1	0	20,6	17,3
2	1	18,3	16
3	2	15,5	13,2

4. Conclusions

The article attempts to assess the influence of the paint coating on the vibration response of a fixed circular plate. The paint applied to the plate had a significant effect on the vibration speed and amplitude. Experimental tests were carried out and a modal FEM analysis of a steel plate with and without paint coatings was performed in terms of the influence of paint coatings on structure vibrations. The results were compared. Similar conclusions were obtained both during model analysis and during real observations. It is noted that applying individual layers of paint to the plate resulted in an increase in the natural frequency of the plate and a decrease in the value of the plate's vibration amplitude under resonance conditions. The obtained test results show that applying paint increases the stiffness of the system.

Additional information

The author declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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