EVALUATION OF QUALITY OF HETEROGENEOUS MECHANICAL SYSTEMS USING IMPEDANCE METHOD

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Summary

The paper analyzes methodology for investigation of dynamic characteristics of heterogeneous systems: honeycomb optical tables and pipelines with sediments, applying mechanical impedance. The developed methodology may be used to assess the quality of plate or cylindrical heterogeneous structures, according to the dynamic characteristics and parameters established in the methodology. It was shown that impedance characteristics are informative to determine some parameters of the quality of honeycomb optical tables and are correlated with the thickness of the pipe's inner sediment layer. Therefore it is possible to choose typical resonance frequencies and according to their changes, the decision about inner layer presence and its value can be made.

Keywords: heterogeneous mechanical systems, quality, impedance, diagnostics.

1. INTRODUCTION

The composite structures are not just used for creation of various constructions in the technology, but they also could be formed as the by-product while implementing some technological processes.

For example, for precise measurements various light honeycomb constructions, which are characterized by optimal ratios of mass, compression strength and bending strength are often used. In this case the quality of composite structure (e.g. the honeycomb optical tables' tabletops (Fig. 1) have been more and more widely applied in laser technologies and nanotechnologies) is related with good dynamic characteristics and properties of vibration damping in vertical and other directions.

The characteristic features of the tables of honeycomb construction are the following: resistance to impact of static and dynamic forces and optimal ratio of mass and rigidity.

The features of honeycomb are determined by core density, size of cells, material, the way of joining (pasting, clinching, welding), thickness and form of walls, fillings, etc. When the core density increases (i.e. the size of cell diminishes), the rigidity, shear module and mechanical connection with upper and lower layers get bigger, and in such a way they improve the characteristics of table. These layers are made from steel, aluminium, plastic and other materials.

The main features of tabletop are the following: local flatness, general flatness, static/dynamic rigidity and maximum relative tabletop motion.

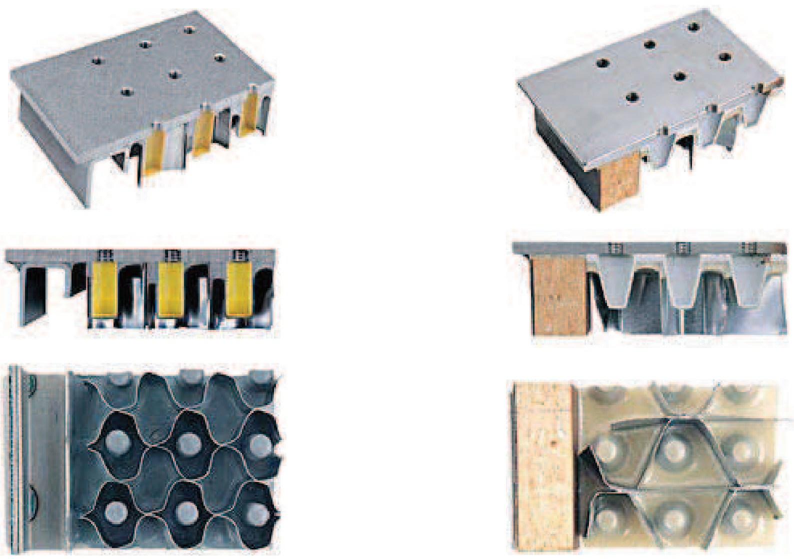

Fig. 1. Examples of Honeycomb Plates' Constructions

All these items describe the main values of concrete quality parameters of table. They are introduced in the producers' catalogues and the consumers may perform the comparative analysis and choose the product suitable for the needs.

The by-product may be the formation of the heterogeneous sediment inside the pipes while implementing the technological processes in the industrial companies, for example while processing the oil inside the pipe the layer of sediments (such as combustion char and like it) is formed. In this case the quality of pipes is related to the thickness of sediment's layers, which affect the dynamic characteristics and efficiency of pipes. The control of the sediment layer is characterized by the fact that the measured dimension is integral in certain distance, which is much bigger than the wall's thickness, e.g., in pipe's section or area, while the volume of measurements, i.e. lengths of pipes, are very big.

In both cases we deal with heterogeneous mechanical systems with special features. In such a way the technology encounters plate and cylinder composite constructions, while it is important for the technological development and safe maintenance to control simply and reliably the quality characteristics and parameters of such constructions.

2. DETERMINATION OF DYNAMIC CHARACTERISTICS OF OPTICAL PLATE OF HONEYCOMB CONSTRUCTION

While assessing the quality of optical tables, it is necessary to prepare and approbate the methodology for determination of dynamic characteristics of honeycomb optical tables.

The features of optical table are characterized by static and dynamic rigidity. The maximum deflection under the impact of static load is considered to be the measure of tabletop's rigidity. Dynamic rigidity describes the resistance of table plate to the impact of vibrations. The dynamic characteristics of the table can be measured the best by dynamic compliance – the dimension that is inverse to the dimension of dynamic rigidity. The dynamic compliance experimental curve may be determined by impedance method. Then the following things may be calculated using experimental data [1]:

1. Dynamic Deflection Coefficient – *DDC* that assesses the relative dynamic characteristics of tabletop. It is determined in compliance curve.
2. Transmissibility of Isolator - *T* – frequentative function of ratio of tabletop's motion and reaction of floor (base) that is expressed in decibels (dB).
3. Relative Tabletop Motion, i.e. relative movement between two points of tabletop. The quicker the motion is, the less possible justiration of the components mounted on the table surface becomes. The relative motion depends not only on the dynamic characteristics of tabletop, but on the characteristics of isolation system and environmental vibrations, as well.
4. Maximum Relative Tabletop Motion is determined after the transmissibility of isolator, factor of compliance strengthening *Q* and power's spectral density are evaluated.

There were experimental tests made for optical plates of honeycomb construction 1HT 12-24-20 [4]. The transmission characteristics were determined by applying mode analysis. The reaction of the object to the strike was fixed by stimulating vibrations in certain points with the help of special strike gauge MODALHAMMER mod. 2302-10, and accelerometer that was fastened near the strike place and connected to analyzer PULSE 3560 (Fig. 2).

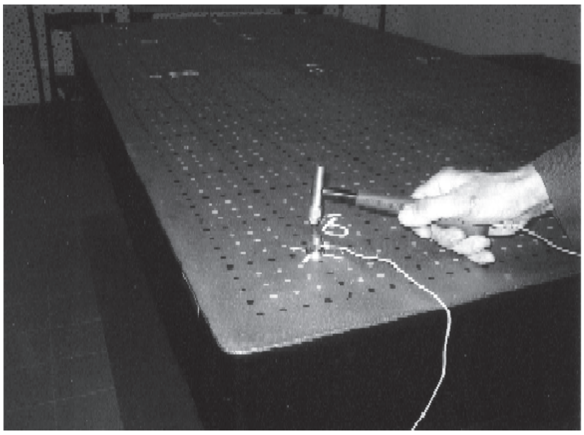

Fig. 2. Determination of Dynamic Characteristics of Optical Plate of Honeycomb Construction 1HT 12-24-20

Due to the created methodology the following items were determined:

- Dynamic compliance (10…1000) Hz in frequency range;
- First resonant frequencies;
- Dynamic deflection coefficient – *DDC*;
- Maximum relative tabletop motion – *MRTM*.

For this purpose the received dynamic compliance curve (Fig. 3) of analyzed plate was used, where two quite high resonant peaks of 199 Hz and 220 Hz may be observed.

The table until 80 Hz is presumed to be a perfectly solid body, where compliance diminishes inversely to square of frequency ($\omega = 2\pi f$). The compliance curve helps the frequencies that are higher than 80 Hz to diverge from the straight line of perfectly solid body. The table cannot be considered to be a perfectly solid body, it starts deforming because of the vibration's impact.

Dynamic Deflection Coefficient (*DDC*) and Maximum Relative Tabletop Motion (*MRTM*) were calculated according to the methodologies of Newport and Melles Griot [2, 3].

The factor of compliance strengthening *Q* of table's point 1 in the resonant frequency f_n is calculated by drawing the characteristics of perfectly

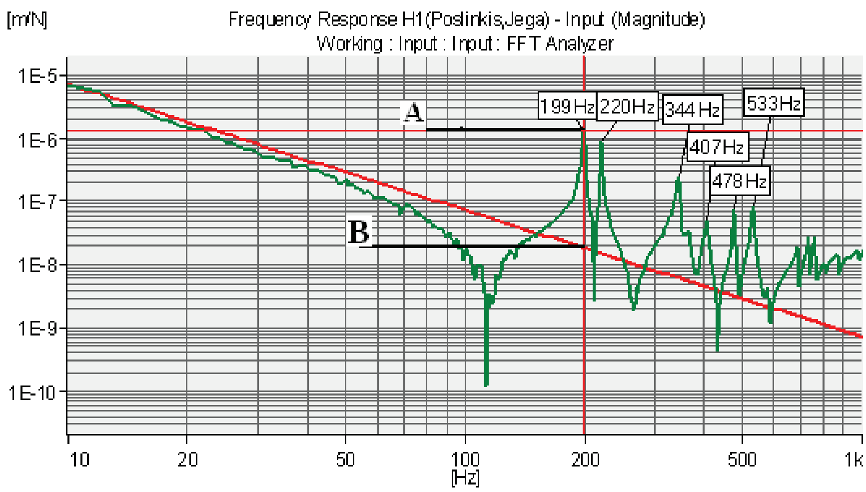

Fig. 3. Dynamic Compliance Curve and Resonant Frequencies (in point 1) of Optical Plate 1HT 12-24-20.

solid body, i.e. the straight line, by the compliance curve (Fig. 3). Starting from the lowest frequency, the compliance curve slopes down without discontinuities until the optical table is rigid and no relative motion is observed on the surface.

The ratio calculated according to the curve of Fig. 3 in the zone of the first resonance (f_n = 199 Hz) is the following:

$$Q = A/B = 71.7$$

Dynamic Deflection Coefficient (DDC) is calculated according to the formula:

$$DDC = \sqrt{Q/f_n^3} = 0{,}00302 = 3{,}02 \cdot 10^{-3}$$

Inverse dimension of dynamic deflection coefficient is $DDC^{-1} = 331$.

Maximum relative tabletop motion is calculated according to the formula:

$$MRTM = CT\sqrt{(Q/f_3^n \bullet PSD)},$$

where: T- transmissibility of isolator, PSD – power's spectral density, C – constant that determines the acceleration units and assesses the worst case between any two points. In the case being analysed C = 0,623 m/s^2; PSD = 10^{-9} g^2/Hz (in the environment close to busy roads); T = 0,01 (accepted according to [3] Melles Griot Super Damp ™ qualitative isolators).

$$MRTM = 0{,}623 \cdot 0{,}01 \cdot \sqrt{\frac{71{,}68}{199^3} \cdot 10^{-9}} = = 0{,}59 \cdot 10^{-9}$$

[mm/s^2].

Such a dimension may be explained by the fact that relative motion of tabletop's point is measured under the impact of 1 m/s^2 acceleration, therefore the value of the maximum relative motion in the point 1 of probative table 1HT 12-24-20 is 0,59 nm.

The calculated maximum relative plate motion is the following:

$$MRTM = 0{,}00176 \cdot 10^{-7} \text{ m m/s}^2 = 0.176 \cdot 10^{-9} \text{ m}.$$

Relative Tabletop Motion (max) in the catalogue of MELLES GRIOT [3] is the following: < 0,18 nm (7·10^{-9} in.)

Consequently, the performed calculations are correct and corresponding to the dynamic characteristics presented in the catalogues [2-4].

3. EXPERIMENTAL TEST OF INNER SEDIMENT LAYER IN PIPES

The known measurement methods of thickness [4, 5] are not effective while measuring the thickness of heterogeneous sediment. Firstly it is explained by a very large number of measurements done in the measurement point in order to receive an integral value in certain range. The sediment layer is honeycomb and it is quite difficult to receive a better reflection from the inner sediment layer that is necessary for resonant or impulse measurement of thickness. According to the tests, the wave interference method [6] that is now used for the control of sediment layer has a number of advantages, but it also has several disadvantages. These could be the fact that the measurements are done when the acoustic transformers are in good contact with the exterior surface of the pipes. This surface is often corrosive, mechanically damaged or difficult to access. In order to overcome these difficulties, the possibility to use the impedance method was analyzed experimentally by determining the existence and thickness of the inner layer of multilayered cylinder system.

The experimental test was done with the steel fragments of the pipes (~1 m length), which have the calibrated thickness of inner sediment layer of 0 mm, 10 mm and 20 mm, the real (formed while exploiting) inner sediment layer from 10 mm to 25 mm, or which do not have any inner sediment layer at all. The external diameter of the fragments of analyzed pipes is 150 mm, inner – 134 mm, their layer of sediment – slash – is formed while using the pipes in oil processing (process of petrol making).

The tests used the method of mechanical impedance in order to compare its possibilities and results with the already approved and analyzed method of interference [6, 7]. The methodology of the mechanical impedance was implemented with the help of the specialized equipment of the company Brüel & Kjær GmbH, Pulse^{TM} 360, with the stroke hammer of the 8202 type and software BZ 7760. Such a set of equipment allowed recording a number of impedance curves, getting their average and analyzing them. The characteristic shock's frequency range is presented in Fig. 4. The registration of the impedance characteristics was done in various points of pipes' fragments in the radial direction and along the pipe.

While analyzing the impedance characteristics, the attention was paid to the changes of their parameters (resonant frequencies, forms, etc.) and their correlation with the condition of pipe's inner layer in the measurement place.

In order to eliminate the pipe's parry conditions, which affect the experiment, we chose the range of frequencies from 500 Hz to 5000 Hz for the test.

The results of the experimental test are shown in Figs. 6–7.

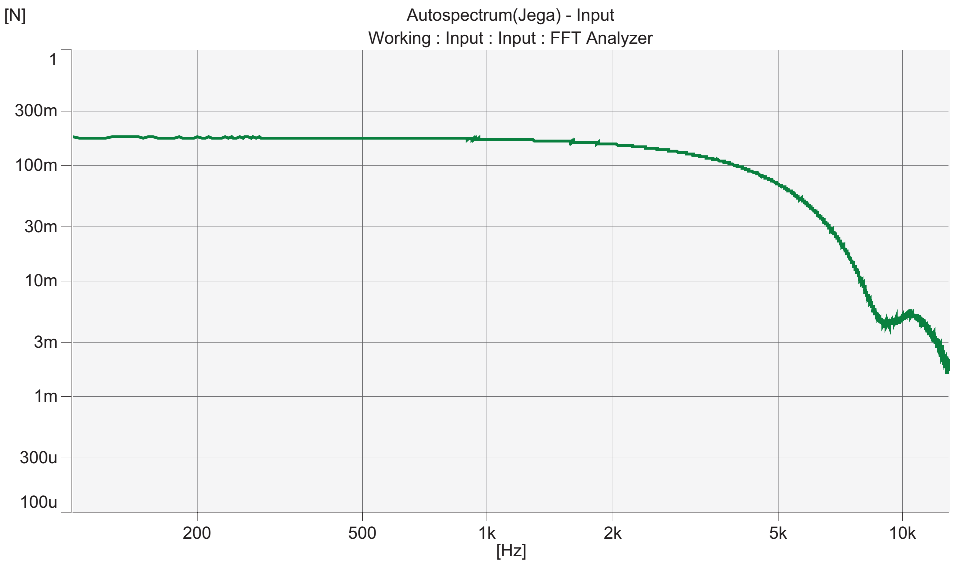

Fig. 4. Mechanical shock's range

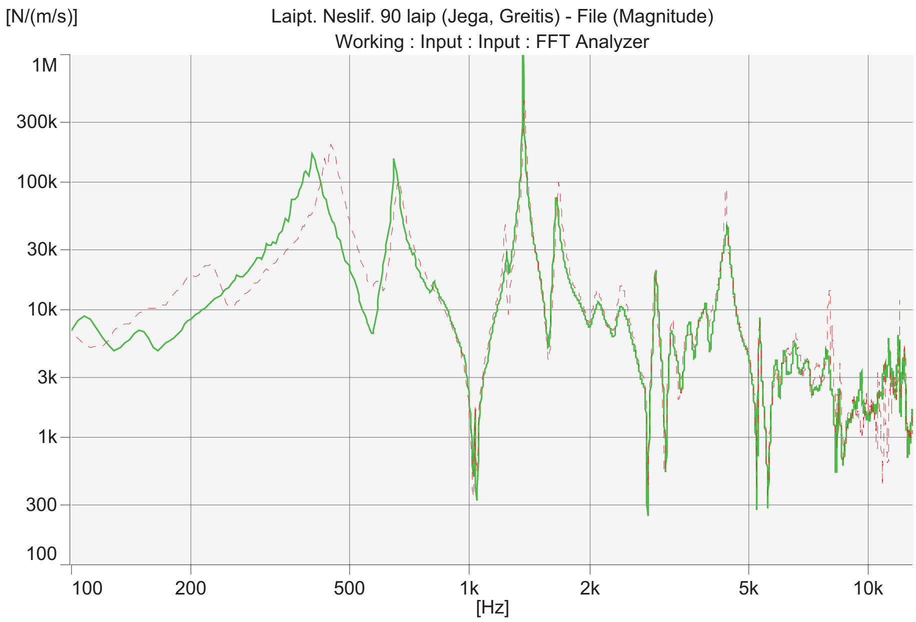

Fig. 5. Impedance of the calibrated pipe with the thickness of slash layer of 0 mm: continuous curve – excitation (stroke by hammer) in the pipe's polished place; spot curve – in the unpolished pipe's place

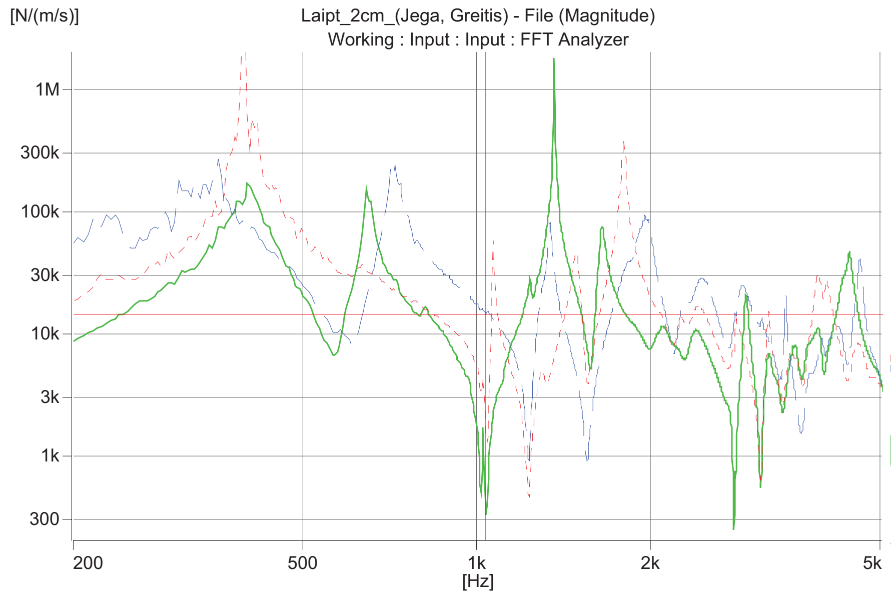

Fig. 6. Impedances of the calibrated pipe: continuous curve – 0 cm of slash (cursor's frequency 1036 Hz); spot curve – 1 cm of slash (cursor's frequency 1040 Hz); stroked curve – 2 cm of slash (resonance frequency 1224 Hz)

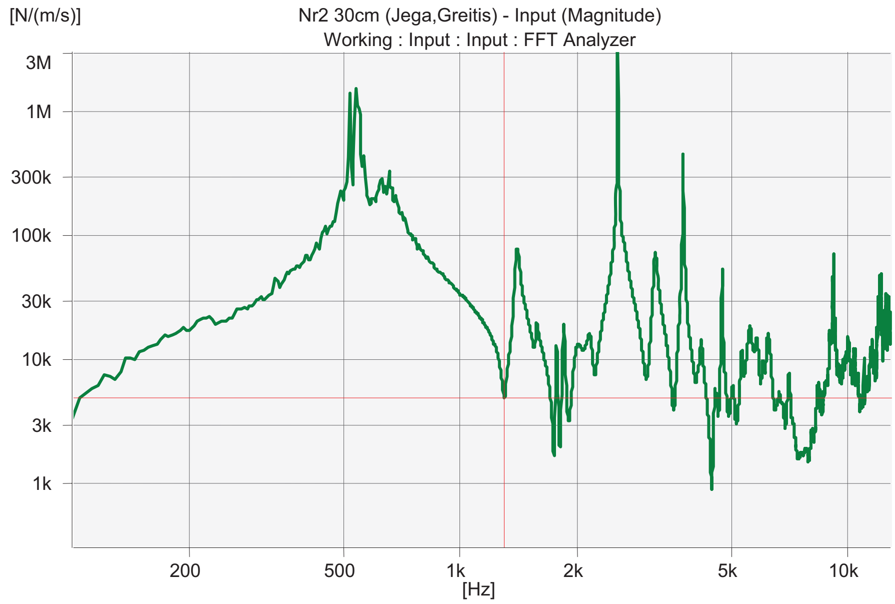

Fig. 7. Impedance of the control pipe with real layer of slash (ca. 25 mm) (cursor's frequency 1296 Hz).

According to the results averaged on the basis of identical measurements, the method of impedance is indifferent to the condition of surface affected by the impulse power in the contact area (see Fig. 5). The impedance characteristics essentially do not differ from 1000 Hz, independently whether the excitation is done in the polished or unpolished part of the pipe. Besides, it has been noticed that the characteristic of the impedance in the pipe with real slash does not depend on the excitation place in terms of average in the analyzed ranges of frequencies.

The results presented in Fig. 6 show the general changing tendency of resonance in pipes without slash and in real pipes with the 10÷20 mm layer of slash. It can be explained by the fact that the casing's resonance in case of n=3 and m=2 (parameters of frequency equation) is about 1020 Hz without slash, while the layer of slash affects more the characteristics of system's rigidity than mass, that is why the resonance (see Fig. 6) has shifted. The impedance of the control pipe (the other pipe that has a 20-25 mm slash layer) in the frequency range of 1000÷1300 Hz showed a similar change. This result is correlated with the impedance characteristics of the stepped (calibrated) pipe. According to the presented results, the resonance frequency changes the most in case of thicker slash layer. This shows that thinner layers change the dynamic characteristics of the mechanical system a little. However after the complete modal analysis is done, it is possible to expect other n, m combinations and relevant frequencies, in case of which this shift may get clearer.

4. CONCLUSIONS

The done tests showed that the measurements of mechanical impedance are informative enough to identify the dynamic characteristics of heterogeneous mechanical systems. In general meaning, the quality of these systems can be defined by certain quantitative parameters, determined from the impedance curves.

The following parameters are determined in case of plane heterogeneous mechanical systems: dynamic compliance, first resonant frequency, dynamic deflection coefficient, maximum relative top motion.

With regard to the cylinder non-homogeneous mechanical systems it was determined that:

- the impedance characteristics are correlated with the thickness of heterogeneous layers of inner cylinder systems;
- the information on the dynamic behavior of cylinder system is received from the impedance characteristics and it allows selecting the frequencies, which are informative for the evaluation of inner sediment layer's thickness;
- the shift of pipe's resonance frequency may be used to create the simple indicator of critical thickness of sediment layer;
- contrary to the Lamb Wave Inference method [6], the impedance method does not need special conditions of acoustic contact.

The developed methodology may be used to assess the manufacturing quality of optical tables, according to the dynamic characteristics and parameters established in the methodology, and to solve the identification task of the technical condition of heterogeneous systems.

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