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EDITORIAL

SPECIAL SECTION

Vibrations, mechanical waves, and propagation of heat in physical systems

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In modern mechanical engineering, vibrations play an extremely important role. Even with small variable loads, the lack of properly conducted analysis of vibrations or dynamic stability may lead to irreversible damage. The use of modern solutions such as the implementation of piezoceramic elements, appropriately selected damping, specially designed heads in loaded slender systems or heat treatment resulting in enhancement of internal structure of the material allows one to design modern and durable structures.

Vibrations of molecules propagating in an elastic medium create mechanical waves. The analysis of this phenomenon in continuous media allows one to produce modern structures such as phononic crystals or metamaterials, which, thanks to their unique properties (the presence of a phononic band gap) leads to the design of devices that control the way energy is transferred in an elastic media. This creates the possibility of manufacturing devices such as acoustic diodes, waveguides, selective filters, mechanical wave mirrors, and many others.

This Special Section of BPAST will be devoted mainly to the selected papers presented at the International Conference "*Applications of Physics in Mechanical and Materials Engineering APMME 2021*" organized online in 2021 by Częstochowa University of Technology. The conference was attended by over a hundred participants from research centers located in such countries as Bulgaria, the Czech Republic, France, Great Britain, Greece, Hungary, Indonesia, Iran, Libya, Malaysia, Poland, Romania, Russia, Slovakia, South Korea, Thailand, and Turkey.

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The main topics covered in the Special Section included:

- Construction of energy harvesting devices using vibrations of beams with piezoelectric elements and permanent magnets allowing one to increase their efficiency.
- The use of heuristic algorithms to optimize parameters in applications in the field of mechanical engineering.
- Predicting the behaviour of vibrating systems in order to increase safety on the example of a coupled payload-vessel system for offshore lifts of light and heavyweight objects.
- Vibration damping control using vacuum packed particles.
- Influence of material properties on vibration frequency (these studies allow one to find the optimum material for the production of a prototype unit).

The paper [1] presents an overview of the recent achievements in the field of mechanical vibrations. First, their application in energy harvesting devices was described. Then, an analysis of the methods of identifying and searching for the most optimal parameters for devices using vibrations was carried out. The third part describes vibration in multi-body systems and modal analysis, and finally describes the properties of granulated materials from which modern, intelligent vacuum-packed particles are made which can be used as intelligent vibration damping devices.

In the works [2, 3], vibrations of beams with a layer of piezoelectric material for energy harvesters were used.

The work of Li *et al.* [2], proposed a four-magnet bi-stable piezoelectric energy harvester (FBEH), which was made of a piezoelectric cantilever beam with a permanent magnet at the end. At the opposite end of the beam, one of the magnets was permanently placed, and the positions of the two additional magnets could be changed horizontally and vertically in relation to the first in order to obtain the highest efficiency with the lowest possible excitation. Using the Hamilton principle, the influence of the resonance frequency, amplitude, and geometry of the system was determined by determining bifurcation diagrams, Poincare maps, phase diagrams, and graphs showing the output power. At low excitation amplitudes, chaotic motion occurred, thanks to which the system showed greater energy efficiency. And the selection of the appropriate geometry facilitated the widening of the operating frequency range. The operating frequency band could also be shifted in this solution, which facilitated more effective energy harvesting from beam vibrations.

The bandwidth improvement in the multi-beam structure has been achieved by the use of dual magnets in a dual cantilever system by Anand *et al.* in the work [3]. In order to generate the appropriate magnetic field strength, the magnets were placed opposite each other, and one was attached to the inner beam and the other to the outer beam. The system was modeled using the Kirchhoff plate theory taking into account the additional magnetic force. The study showed that adding the magnetic tip mass to the dual-beam structure improved the operating frequency range, output voltage, and output power. Compared to single beam rectangular structures, the dual beam structures significantly improve the frequency bandwidth.

The works [4, 5] show how the heuristic search algorithms of the state space of solutions, such as genetic and particle swarm algorithms, can be used to find the optimal parameters of a given model.

In the work by Kwiatoń *et al.* [4] two heuristic algorithms were used, namely the genetic algorithm and the particle swarm optimization algorithm to find the parameters of the discrete-continuous model represented by the stepped cantilever beam. The translational and rotational spring constants of the considered system were sought. The properties of the stepped cantilever beam were analyzed using Timoshenko's theory. The formalism of Lagrange multipliers was used to formulate and solve the problem of free vibrations. The use of the natural frequencies of the modelled object obtained as part of the conducted experiments facilitated the validation of the algorithms used. For both algorithms, similar values of constants were obtained. The use of the methodology presented in the article allows one to determine the influence of the geometry of a given system on its vibrations without additional experimental research.

Two types of genetic algorithms were compared in the work of Garus *et al.* [5]. One genetic algorithm was characterized by a constant number of layers (GACL) in all populations in a single run. The procedure was called for each number of layers from the analyzed solution space, and then the most advantageous of all found structures was extracted. In the second genetic algorithm, individuals in the population were characterized by a variable number of layers (GAVL) and a single run of the algorithm was sufficient to find the optimal structure. The aim of the study was a multi-criteria optimization of the distribution of layers of the quasi-one-dimensional structure made of glass and polyvinyl chloride (PVC). Lossy materials were not analyzed in the study so that the transmission was minimized only as a result of destructive interference inside the structure. Each of the algorithms had dedicated objective and crossover functions. The objective function was responsible for minimizing the transmission of mechanical waves propagating in the analyzed structures and the elimination of high transmission peaks with a small half-width. Moreover, in the objective function of the GAVL algorithm, the number of layers in the structure was taken into account, so that structures with a smaller number were rewarded. The transfer matrix method algorithm was used to determine the transmission of the mechanical wave in the range of acoustic frequencies. In order to minimize finding the algorithm in the local minimum of the solution space, in each population with the assumed low probability, there was a mutation of individual layers, and two new random structures were added. There was a significant reduction in transmission for all the structures obtained. In the structures obtained using the GACL algorithm, there were narrow peaks, but their intensity was 60 dB lower than that of the input signal (90 dB). On the other hand, the most favourable results were obtained with the use of the GAVL algorithm, where high transmission peaks were not observed, the solution was found in a much smaller number of computational steps, while simultaneously searching a larger range of the state space of solutions to the assumed problem, and the obtained structures consisted of a smaller number of layers.

Mackojć and Chiliński in [6] applied the methodology facilitating payload-vessel system analysis, where mutual interactions of the system dynamics for lifting in the air were investigated in particular. Loading the load by external forces may lead to the phenomenon of parametric or forced resonance, which in turn may lead to the destruction of the system or may pose a threat to the operator's life. The proposed solution facilitates predicting the possibility of resonance. The model described in the article consists of a lifting system with three degrees of freedom and a vessel with six degrees of freedom. The work includes the excitation function at the tip of the vessel crane using the response amplitude operators (RAOs) processing methodology. The dynamics of the system in the phase of lifting the load in the air is comprehensively tested with the use of a coupled system, which takes into account changes in the system parameters.

However, sometimes vibrations can lead to the phenomenon of resonance and destruction of the system in which they propagate. The most effective way to dampen unfavourable vibrations is to use damping devices. Modern solutions facilitate controlled properties of vibration damping devices, and vacuum-packed particles are a special case, examples of which are presented in the works [7, 8].

Vacuum-packed particles have also been used by Bartkowski *et al.* in work [7] to develop the concept of the adaptive crash energy absorber. The presented design of the device collects data from the environment using the mounted sensors, such as the position and speed of movement of objects. Then, the computer analyzes them and, after detecting a collision threat, determines the optimal energy dissipation strategy, which allows you to adjust the absorber negative pressure value. After the impact energy is dissipated, the system returns to its previous state. A plasticity model was proposed for numerical analysis, which is an extension of HMH rules, using the Johnson–Cook model. Then the model was experimentally validated on a prototype device.

The last application of vacuum-packed particles was the work of Rodak *et al.* [8] which presents the use of a linear damper as a supplementation for a viscous shock absorber in blast mitigation seat in military armoured vehicles. The linear VPP damper and the viscous damper were installed parallelly. The paper compares the results of laboratory tests carried out on the shock bench with the results of field tests. The Hybrid III anthropomorphic test device dummy was used to collect acceleration. Numerical simulations were performed using the model of the viscoplasticity by the Johnson–Cook. The contact between the ground and the vehicle has been modelled through the Hertzian contact theory. The presented research showed the effective possibility of the VPP damper application.

In [9] Sokół and Pierzgalski have studied a new design of suspension which can be used in unmanned vehicles that are often used in everyday life, mostly by rescue teams or scientists during the exploration of new terrains. The studied six-wheeled mobile platform can dynamically change the wheel base in relation to the area of action or terrain inclination angle. The active change in the location of the center of gravity creates a possibility to access sloppy obstacles not available with classical suspensions. The main scope of this study was to investigate the influence of material properties on the vibration frequency of mobile platforms at different lengths of suspension members. The obtained results will facilitate finding the optimum material to produce a prototype unit.

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REFERENCES

[1] S. Garus *et al.*, "Mechanical vibrations: recent trends and engineering applications", *Bull. Pol. Acad. Sci. Tech. Sci.*, vol. 70, no. 1, p. e140351, 2022, doi: 10.24425/bpasts.2022.140351.

[2] X. Li *et al.*, "Investigation to the influence of additional magnets positions on four magnet bi-stable piezoelectric energy harvester", *Bull. Pol. Acad. Sci. Tech. Sci.*, vol. 70, no. 1, p. e140151, 2022, doi: 10.24425/bpasts.2022.140151.

[3] A. Anand, S. Pal, and S. Kundu, "Bandwidth and power enhancement in the MEMS based piezoelectric energy harvester using magnetic tip mass", vol. 70, no. 1, p. 140149, 2022, doi: 10.24425/BPASTS.2021.140149.

[4] P. Kwiatoń, D. Cekus, M. Sofer, and P. Sofer, "Application of heuristic methods to identification of the parameters of discrete-continuous models", *Bull. Pol. Acad. Sci. Tech. Sci.*, vol. 70, no. 1, p. e140150, 2022, doi: 10.24425/bpasts.2022.140150.

[5] S. Garus, W. Sochacki, M. Kubanek, and M. Nabiałek, "Minimizing the number of layers of the quasi one-dimensional phononic structures", *Bull. Pol. Acad. Sci. Tech. Sci.*, vol. 70, no. 1, p. e139394, 2022, doi: 10.24425/bpasts.2021.139394.

[6] A. Mackojć and B. Chiliński, "Preliminary modelling methodology of a coupled payload-vessel system for offshore lifts of light and heavyweight objects", *Bull. Pol. Acad. Sci. Tech. Sci.*, vol. 70, no. 1, p. e139003, 2022, doi: 10.24425/bpasts.2021.139003.

[7] P. Bartkowski, H. Bukowiecki, F. Gawiński, and R. Zalewski, "Adaptive crash energy absorber based on a granular jamming mechanizm", *Bull. Pol. Acad. Sci. Tech. Sci.*, vol. 70, no. 1, p. e139002, 2022, doi: 10.24425/bpasts.2021.139002.

[8] D. Rodak, M. Żurawski, M. Gmitrzuk, and L. Starczewski, "Possibilities of Vacuum Packed Particles application in blast mitigation seat in military armored vehicles", vol. 70, no. 1, p. e138238, 2022, doi: 10.24425/BPASTS.2021.138238.

[9] K. Sokół and M. Pierzgalski, "Investigations on an influence of the material properties on vibrations of active Rocker-Boogie suspension", *Bull. Pol. Acad. Sci. Tech. Sci.*, vol. 70, no. 1, p. e138239, 2022, doi: 10.24425/BPASTS.2021.138239.

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