INNOVATIVE APPLICATIONS OF ACOUSTIC WAVES FOCUSATORS

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Abstract. Here, we propose and investigate designs for devices which use acoustic wave focusators. We have modeled the processes involved by use of the ANSYS software. This was done in order to demonstrate the efficiency of diffractive acoustic elements for mixing particles of different densities and for damping high-frequency vibrations. The proposed designs and technological solutions could be used effectively for mixing reactive substances of various fractions and for damping the effects of high-frequency vibrations on precise measuring instruments.

Keywords: focusators of acoustic waves, acoustic diffractive elements, numerical modeling, mixing system, damping system of high-frequency vibrations.

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Introduction

Acoustic technologies are used extensively in various branches of science and technology [1-3]. For example, acoustic logging is used when exploratory geological work is undertaken [4].

In this article we suggest using “backlog” - which was developed at the Image Processing Systems Institute of the RAS (IPSI RAS) [5] for laser radiation focusing [6-8] -for acoustic wave focusators instead.

The design and technological groundwork revealed the efficiency and the operability of the laser radiation focusators for branding, thermal processing, cutting and monitoring of various parameters, etc. [6-12]. Laser radiation focusators have been under development for the last 35 years, and their use in investigations has led to a large number of different methods being worked out in respect of this use: asymptotic [13-15], iterative [16-17], and numerical [18-19] methods of analysis; conformable software for design [20-23] and modeling [24-28], polymeric [29], plasmachemical [30-33], mechanical [34],and laser [35-36] methods of production, also instrument facilities and experimental exploratory procedures [37-40].

Research work [8] has demonstrated the possibility of applying diffraction acoustic elements (DAE) to the mixing of components of various dimensions, and for damping high-frequency vibrations. However, the work [8] does not present any data which confirms the introduced design's operability.

The purpose of this article is, essentially, the numerical simulation of our designs for the corroboration of this design's operability, and in order to determine the operating conditions of the vibromixer and damper.

Problem formulation

The problem of mixing various fractions of particles occurs in many economically important branches of technology: powder metallurgy [41], bubbling and mixing of the solid particles in reactors for fine chemical manufacture [42], in construction materials production [43], agriculture [44], et al. The distinguishing characteristics of these mixing operations are their operation at high energy intensities and the requirement to use costly equipment. For all these reasons, existing techniques related to this kind of mixing operation are unacceptable for many engineering problems: for example, in the small agriculture sector. Thus, at this time, there are many new engineering problems which demand new solutions. Fine-dispersed substance mixing (including nanoparticle mixing) faces the challenge of particle "agglutination". At present, there is no effective technique which can effect the mixing of microparticles in an economically viable time.

High-frequency vibration damping is a topical problem in precision mechanical and instrument engineering. At present, active damping systems are considered to be the most effective [45-46]. However, these systems are insufficiently failsafe due to the large number of components of which systems such as this comprise. The development of an inexpensive and failsafe damper design, which is capable of diffusing the energy of the high-frequency harmonic components of vibrations, would be useful for many industry sectors: mechanical engineering, instrument engineering, fine chemical production et al.

Testing technique

The detection of the capacity for momentum impartation of particles inside the receptacle, via the bottom vibration, was carried out by use of the ANSYS Workbench software. The receptacle was assumed to be an axisymmetric receptacle with a cylindrical form. The inner diameter of the receptacle base was 90 mm and the wall thickness was 2.2 mm; the receptacle height was 100 mm. For the receptacle wall, the material that was chosen was cast iron (State Standard 1412-85: Cast iron with the vermicular graphite); this has a high vibration energy absorption coefficient and is reasonably priced. Steels and alloy materials of domestic manufacture are absent from the ANSYS software library of materials; therefore, the foreign analog of the cast iron, GG-30 (DIN 1691), was used for the calculation.

It was assumed that all the particles, involved in the mixing process, were spherical in form, and all had an outer radius of 8.25mm (R_{sph} = 8.25 mm). On the other hand, density and elastic properties could be of two types. The density of the solid spheres corresponded to the packed density of granulated polycarbonate (700 kilograms per cubic meter), and the elastic properties corresponded to those of monolithic polycarbonate (compression modulus of elasticity E = 2400 MPa, Poisson's ratio– 0.39). This selection of density values and sphere elasticity properties was made in order to coincide with those of pelleted mixed feed density and elasticity properties (GOST R 51899-2002 Pelleted mixed feed). The vibromixer is intended to be used for agricultural purposes.

Not only solid spheres, but also hollow spheres were used in the mixing operation. The hollow sphere’s material corresponded to the chosen polycarbonate properties. But the inflexibility (the capability to resist deformations) of the hollow spheres differed from the solid sphere’s relative inflexibility. The modeling process allows for the mixing of spheres with various inflexibilities, and the numerical model is approximated to the real mixing process. The wall thickness of the hollow spheres was 3.25mm.

The simulation of the damping process included solid titanium spheres only (the properties of solid titanium, as represented by the ANSYS database, correspond to the properties of the real world material to which this study relates). The damping, housing and physical-mechanical properties corresponded to the vibromixer receptacle characteristics.

For the real world vibromixer design, it was proposed that the vibration source should generate vibrations with a frequency of 100 Hz, and an amplitude of 1mm. Vibration modeling was effected by segmenting the receptacle base, these segments moved apart from each other under the sine law.

The modeled mixing process was carried out for 1.5 sec. The required computing time was 24 hours.

Vibrating mixer

The vibrating mixer design [47-48] was examined in order to demonstrate the advantages of using diffraction acoustic elements.

The vibromixer design, for agricultural purposes, is shown in figure 1. In this case, components with five different dimensions (fractions) and inflexibilities are mixed.

The mixing process of the components, 5, is the result of the rippling effect of the vibrator, 2, which generates acoustic spectrum vibrations. Vibrations are transmitted through the diffuser, 3, to the operating surface of the DAE, 4. The Vibratory-active surface of the diffraction acoustic element, 4,concentrates acoustic waves to the circles on the conical surface by the use of distinct elements in the form of Fresnel circles. Particles of the mixing components, 5, placed on the conical surface, receive some kinetic energy; consequently, a “reduced” layer of the particles, of component 5, is formed on the conical surface. Particles of component 5, having a certain ratio of dimensions and distances between adjacent circles on the conical surface, roll down along the conical surface. The mixing particles of components 5 from the upper layer then take their place. The design of the receptacle, filled with spheres, was examined in the ANSYS software in order to check the efficiency of the vibromixer operation. The DAE microrelief was applied on the receptacle base.

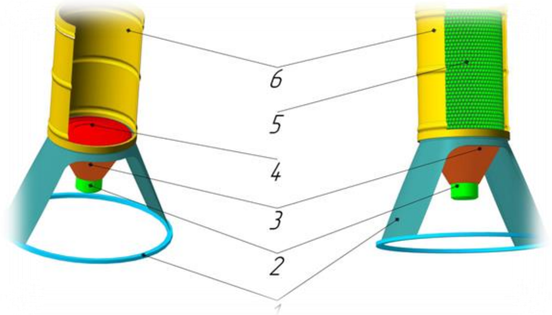

Fig. 1. Vibrating mixer (agricultural version): 1 – stanchion; 2 – vibrator; 3 – diffuser; 4 – diffraction acoustic element; 5 – mixing components; 6 – receptacle

The evolution of the mixing of the spheres with various inflexibilities in 1.5 seconds is shown in figure 2. Figure 2a presents the mixing process at time t = 0.4 seconds after mixing was started. Figure 2z presents condition time t = 1.5seconds after mixing was started. Figures 2b-2f presents the interim conditions at intervals of 0.25 seconds.

The evolution of the spheres, in terms of repositioning, indicates the effectiveness of the mixing process. The model tests showed that effective mixing is realized with a certain ratio of sphere (component 5) dimensions to wavelength (of the longitudinal acoustic radiation):the nearer the vibration wavelength is to the particle's diameter, the less time is required for the mixing.

It became apparent that heavy spheres (in component 5) were able to move down to the base,4, of the receptacle, 6, and, when the sphere then received an impulse, would be able to force out a minimum of two lighter spheres from above. This action of the heavy spheres needs the acoustic radiation wavelength value to be very close to the sphere's diameter. It should be noted that the diameter of the spheres (in 5) should not be a multiple of the diameter of the receptacle; otherwise jamming of the spheres in one horizontal line can take place. This jamming could decrease mixing efficiency. Asymmetrical disposition of cut of the receptacle, 6, in the horizontal plane obviates these difficulties (i.e., the jamming of the mixing spheres, 5).

It should be noted that the mixing of powders with nanodimensions is possible, using this design, provided that the necessary acoustic wavelength is obtainable. The use of diffraction acoustic elements makes it possible to mix particles of various fractions inside a hermetic receptacle. This condition is reliable for operation with reactive substances.

The vibromixer design is patented [47-48]. Attributes of the design are as follows: a low expenditure of energy, manufacturability and reliability.

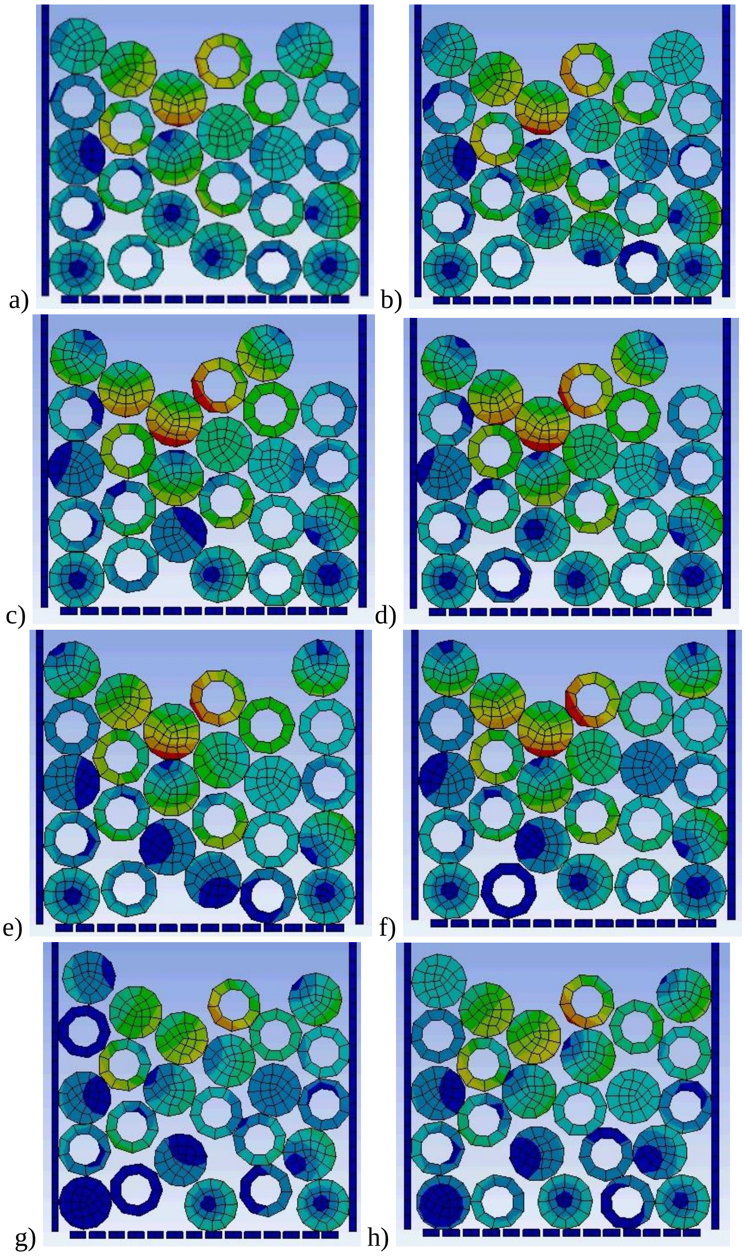

Fig. 2. Evolution of the mixing of the spheres of one radius, but variable densities and elastic properties (starting time $t = 0.4$ seconds, time interval of the fixing of the sphere location in the receptacle – 0.25 seconds)

High frequency damper

High frequency irregular vibrations are rarely isolated during the carrying out of high-frequency operations. Impulse vibration stresses occur in machine-tool building and instrument engineering -for example, when the tool falls down accidentally; in terms of guidance systems, the vibrations could be from a geological source or they could be vibrations from the operating equipment.

A high frequency damper [49] is proposed which will decrease the influence of these irregular impulses upon high-frequency systems operation. The engineered design makes it possible to damp high-frequency vibrations via vibration energy dissipation (figure 3). For this purpose, vibrations encountered by the high frequency damper are passed from the base, 1, to the diffraction acoustic element, 4, with microrelief - which focuses the vibration energy onto the spheres, 5. The focus of DAE 4 has to be located outside of the damper's cover, 3. The spheres, 5, start to interact chaotically with each other as a result of the vibration influence from the damper base, 1, and energy dissipation of the impulse vibrations occurs. The spheres, 5, occupy no more than half of the capacity of the bushing, 2, while simulating the damping process(fig. 4). This damper design is patented [49].

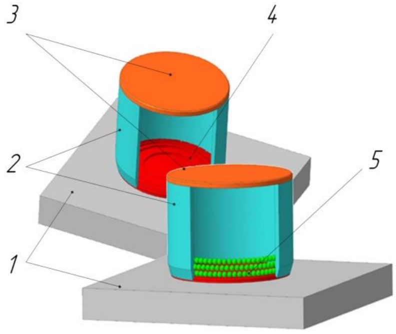

Fig. 3. High frequency damper design: 1 - base, 2 – cylindrical bushing of the damper, 3 - cover, 4 – diffraction acoustic element, 5 - spheres.

Figure 4 shows the evolution of the mixing of the titanium spheres, 5, via acoustic vibrations of the damper base, 1, over 1.5 seconds. Figure 4a presents the damping process at time $t = 0.4$ seconds after mixing has started. Figure 4h presents condition time $t = 1.5$seconds after mixing was started. Figures 4b to 4f present interim conditions at intervals of 0.25 seconds.

From figure 4, we can see that the acoustic energy dissipation of the base, 1, through the spheres, 5, occurs with sufficient efficiency. The more weight the spheres have, the more inert is the damper's response to vibrations: i.e. the longer the vibration wavelength is, the more weight the damper spheres should have.

Numerical experiments showed that the less weight the spheres have, the more dynamic the damper operation is (the less the starting time of the spheres is). The damper could be customized to the filtration of vibrations of specific frequencies by changing the weight of the spheres in 5.

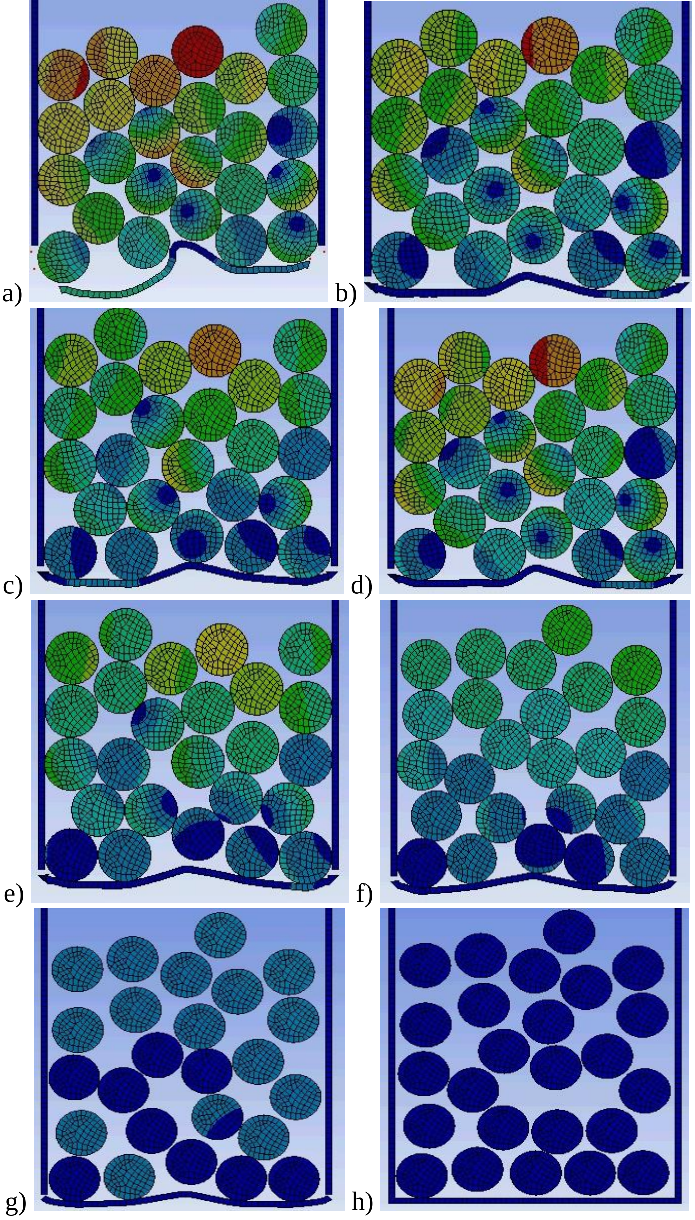

Fig. 4. Evolution of the mixing of the spheres of the same radius, density and elastic properties (starting time $t = 0.4$ seconds, time interval of the fixing of the sphere location in the receptacle – 0.25 seconds)

The ability to fill the cylindrical bushing, 2, by spheres (from 5)with various forms, dimensions, and densities, along with the ability to change the quantitative ratio of the various fractions of the damping elements (spheres, 5) make it possible to damp impulse vibrations selectively. Because of this, new manufacturing capabilities, for example, liquid emulsifications and others are opened up.

Conclusion

In this article we proposed two designs: that of a vibromixer and that of a high frequency damper. We proposed a methodology for the identification of reasonable design solutions in relation to the vibromixer and the high frequency damper design process. This methodology used the ANSYS software.

Designs, similar to the vibromixer's, could be used for liquid emulsification.

The simulation of the mixing processes of particles with various densities in the ANSYS software demonstrated the efficacy of using a diffraction acoustic element for this. Also, it was found that using a DAE for the damping of high frequency vibrations resulted in an acceptable level of damping of certain harmonic components of the vibration spectrum.

Using the "backlog" - developed at the Image Processing Systems Institute of the RAS (IIPS RAS), for use in the field of optical instrument engineering [50-64] and diffraction nanophotonic [65-74] - for the designing of diffraction acoustic elements with certain characteristics would seem to be a very promising direction for future work.

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