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MATHEMATICAL MODELING OF A COMPLEX PROBLEM OF ACOUSTIC IMPACT ON AIRBORNE PARTICLES THROUGH RESONATORS

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Air pollution in large cities and industrial centers is a major issue. Solving this issue requires new solutions, the feasibility of which can be confirmed by mathematical modeling. ANSYS is a powerful tool capable of solving complex problems related to air purification. It integrates various simulation modules—Modal, Harmonic Response, Harmonic Acoustic, and Fluent—allowing for comprehensive modeling and analysis. ANSYS enables the use of results from different modules as initial or boundary conditions for subsequent simulations, making it ideal for tackling multifaceted challenges in air quality management through methods like acoustic coagulation.

One of the biggest problems in big cities and industrial centers is air pollution. The air contains both solid and liquid particles and living microorganisms, with a concentration of up to 10^9 particles per cubic meter. Some of the airborne particles can cause only unpleasant sensations: the desire to cough or some allergic symptoms. Others can cause diseases that pose a direct threat to human life, as they can penetrate blood vessels. They can cause coronary heart disease, strokes, and chronic obstructive pulmonary disease, which are responsible for one third of the most common causes of death on Earth. And these particles are PM 2.5.

The sources of PM2.5 particles are internal combustion engines and industrial processes involving the combustion of solid fuels (coal, lignite, oil), construction, mining, many types of production (especially cement, ceramics, brick, smelting), and in cities, road surface erosion and abrasion of brake pads and tires can be a source. In September 2021, the WHO updated its global air quality guidelines for the fine particles (PM2.5 and PM10) [1]. Currently, the WHO recommends a maximum level of 5 $\mu g/m^3$ for fine particles PM2.5 for long-term exposure to protect health. The average concentration of such particles in Kyiv in 2023 was 9.3 $\mu g/m^3$, which is twice as high as the WHO standards [2].

To reduce the number of airborne particles, there are several different approaches, including: filtration, acoustic coagulation, sedimentation in an electric field, sedimentation in a magnetic field, and the use of absorbers and scrubbers.

Filtration is considered to be the most effective way to capture particles. Thus, HEPA filters can capture up to 99.995% of particles up to 0.3 microns in size. But such filters are relatively expensive, need to be replaced after a certain number of particles is accumulated, consume a lot of energy to pass through the barrier, and require preliminary air purification in case of a large number of contaminants. Therefore, they are not used to clean the exhaust air of heavy industry.

Therefore, for industrial use and purification of large quantities of air, it is more expedient to use other methods, in particular, acoustic coagulation. This approach consists in "sonicating" the air volume with acoustic waves. Studies have shown the effectiveness of this method. However, researchers cannot come to an unambiguous conclusion about the frequency of oscillations for effective coagulation. In addition, a large amount of energy is required to purify a large volume of air.

To increase the efficiency of acoustic coagulation units and their possible further use for industrial-scale air purification, it is necessary to improve their designs. In particular, more efficient propagation of acoustic waves in the medium and increased efficiency of emitters. Such a solution is proposed in the project "Investigation of the influence of resonant phenomena of acoustic coagulation in air purification" by using additional resonators to enhance the coagulation effect and increase the obstacles to the particles.

Changes to the design require a feasibility study to verify the use of this solution. Conducting a physical experiment requires large expenditures for creating a test bench and conducting various studies to determine the degree of interaction of quantities. Therefore, the first step in solving such a complex problem is to build mathematical models and solve them using computer modeling.

The complex problem to be considered in the project is to solve the following problems in a sequential manner:

1. Determination of the natural frequencies of resonators and vibrations under the action of an ultrasonic emitter.
2. Establishing the laws of propagation of acoustic vibrations through resonators into the acoustic medium.
3. Determination of the degree of influence of vibrations on particles in the air and their ability to coagulate.

To solve such a complex problem, it is advisable to use computer modeling systems such as COMSOL Multiphysics or ANSYS. Both of them are based on the finite element method.

After analyzing the available solvers in both systems, ANSYS was chosen, namely:

- «Modal» will be used to determine the natural frequencies of resonators by the method of vibration analysis;
- «Harmonic Response» will be used to determine the resonance manifestations in the coagulation system;
- «Harmonic Acoustic» will be used to determine the regularities of acoustic wave propagation in the air;
- Computational fluid dynamics «Fluent» will be used to determine the effect of resonators on the hydrodynamics of the fluid flow anb behavior of the particles.

The solution of complex problems in ANSYS is realized through the possibility of using the simulation results obtained in different systems as initial or boundary conditions for subsequent systems (Fig. 1). To transfer the results obtained in the first three stages to the Fluent system, the Fluid-Structure Interaction FSI is used, i.e., the physical presence of resonators is replaced by a boundary condition at the interface with the acoustic medium.

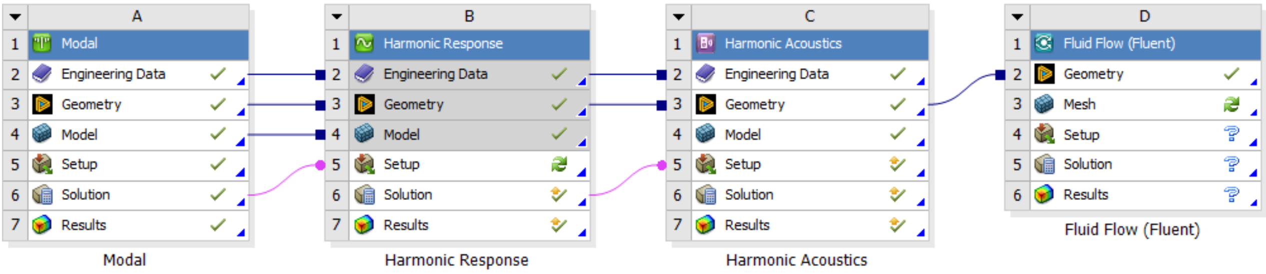

Fig 1. *Workbench of complex problem*

Thus, ANSYS has the ability to solve complex problems, with their preliminary breakdown into simple ones and the correct connection of meaningful blocks. For more advanced configuration of initial and boundary conditions, as well as modeling parameters, ANSYS has its own built-in programming language APDL (ANSYS Parametric Design language).

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References

1. European Environment Agency (2023) *World Health Organization (WHO) air quality guidelines (AQGs) and estimated reference levels (RLs)* [online]. URL : https://www.eea.europa.eu/publications/status-of-air-quality-in-Europe-2022/europes-air-quality-status-2022/world-health-organization-who-air.
2. IQAir (2024) *Interactive global map of 2023 PM2.5 concentrations by city* [online]. URL : https://www.iqair.com/world-air-quality-report.
3. Shi Y., Wei J., Bai W., Zhao Z., & other. (2023) Theoretical analysis of acoustic and turbulent agglomeration of droplet aerosols, *Advanced Powder Technology*, 34 (10), 104145.