Wind energy, a new direction of the Balabekov School on the Karman vortex street

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Abstract. The article presents the main directions, achievements of the academic school of academician O.S. Balabekov. The application of the main developments in renewable energy sources, that is, using the kinetic energy of the wind in the generation of electricity, increasing efficiency due to the simultaneous vortex formation mode. To do this, a laboratory unit with a regular structure of the transducers was designed. Describes in detail the process of simultaneous vortex formation to improve performance, with the same structural and operational parameters of the installation. The optimal location parameters of the vibrating elements in the working area of the installation are determined. The vibration frequency and vibration amplitude of the plates are determined.

Keywords: Energy conversion, vortices, simultaneous vortex formation, radial step, vertical step, Balabekov School.

1. Introduction

Theodor von Kármán assumed both the Chair of Mechanics and Chair of Aerodynamics as well as the leadership of the Institute of Aerodynamics in 1913 [1]. Through his work, especially in the area of fluid mechanics, von Kármán created a worldwide reputation for himself. In addition to his activities in Aachen, in 1930, he took over the direction of the Guggenheim Aeronautical Laboratory at the California Institute of Technology in Pasadena. In 1912, Karman carried out a theoretical analysis of an incompressible fluid flowing around an extended axis perpendicular to the direction of motion of a continuous medium. Obtained in this chain of vortices called Karman vortex street in his honor.

The study of the flow around single bodies and their systems with different relative positions began with the solution of some practical problems that arose first in aerodynamics (double struts for attaching wings), and then in hydrodynamics (vibration of the periscope and radar masts), in construction mechanics (double smoke pipes in conditions of wind blowing, dams and offshore structures in conditions of strong waves), in electrical engineering (vibration of a power line with two or more wires),

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in applied mechanics (vibration of pipes in heat exchangers) and in chemical engineering (forces acting on a bundle of pipes) etc.

At the scientific school of academician of NAS RK Balabekova O.S “Theoretical foundations of processes and apparatuses of chemical technology and industrial ecology”, one of the areas of research is the establishment of patterns of interaction of vortices when flowing around a continuous stream of discretely located bodies, on the basis of which fundamentally new classes of heat and mass transfer, gas-cleaning and dust collecting devices have been created [2-5].

In the process of research, it was found that two bodies streamlined by a stream behave similarly to a single body only when both are far enough apart from each other. A study of the influence of distance on the patterns of flow around two or more bodies indicates unexpected distributions of forces and pressure, intensification or weakening of the vortex convergence process. In this case, the research task, in each of the above cases of flow around structures and equipment elements, was to determine such distances that affect the intensity of the interaction of the vortices.

After a comprehensive analysis of the laws of electro-radio engineering, hydraulics and the accepted hypothesis about the analogy of wave processes in these areas of knowledge, it was found that the anomalous nature of the detected phenomenon is explained by new patterns of vortex formation and interaction in a stream moving along and across discretely located bodies.

A large number of works are devoted to certain aspects of the flow of a stream through a system of bodies. Therefore, without stopping at a detailed analysis of them, we will single out only those patterns that were established in the research process:

- depending on the flow regime, stationary (periodic) and unsteady oscillations of the flow generated by the vortices as well as the bodies themselves arise, the frequency and amplitude of which depend on the flow velocity, profile and dimensions of the body, deformation and the imposition of bonds between the bodies;
- the head element controls the pulsation of the flow and the drag coefficient of the subsequent body, feedback is observed only at a step less than the size of the vortex;
- the frequency of vortex disruption, as a rule, is the same on the head and tail elements, i.e. vortex formation occurs synchronously;
- the distance of the vortex following (the distance between adjacent vortices in the direction of their movement) is constant and depends only on the shape and size of the body, provided that the vortex chains are stable;
- with a radial arrangement of the elements, the vortex coupling between them is broken at a step greater than the transverse size of the vortex, depending only on the width of the streamlined body;
- at a certain step between the bodies located along the flow, depending on their shape and size, the total resistance exceeds the arithmetic sum of the resistances of individual bodies and reaches a maximum.

According to the results of studies by the Russian Academy of Natural Sciences, the International Academy of Authors of Scientific Discoveries and Inventions, the International Association of Authors of Scientific Discoveries, Academician OS Balabekov opening diplomas were issued with students.

Diploma No. 144, [6] according to which the previously unknown regularity of the interaction of vortices arising from the separated flow of a gas or liquid flow through discrete bodies located along it, which consists in the fact that the resulting vortices from the head elements cause a time shift during the formation of vortices on subsequent bodies, moreover, when a common-mode vortex formation occurs, extreme values of the hydrodynamic and heat and mass transfer characteristics of the flow are observed.

Diploma No. 269 [7] according to which a previously unknown regularity was established for the formation and interaction of vortices when a stream of gas or liquid flows around discrete bodies perpendicular to it, as well as holes of various geometric shapes, namely that there is a certain critical distance, expressed as the ratio of the step between elements (holes) to their characteristic size, which determines the mechanism of vortex formation, before which the mechanism of vortex formation and interaction is characterized by the width of the gap between the bodies or the jumper between adjacent holes, and its excess by the width of the streamlined bodies or the size of the holes, the values of
hydrodynamic and heat and mass transfer flow characteristics in the subcritical region exceed similar values of supercritical indicators.

The main provisions of scientific discoveries can be taken into account:

- in mechanical engineering when designing tube bundles in shell-and-tube heat exchangers, internal devices of extractors, distillation columns, evaporators, mixing devices in vessels with mixers, etc;
- in power plants during the design of nuclear reactors, pulsed combustion devices with flow turbulators, turbines of power plants;
- in aerospace engineering when placing rocket stages, equipping them with shuttle shuttles, designing fasteners on small aircraft;
- in construction during the design and construction of high-rise buildings, chimneys, sea dams, relay masts, power lines, television towers, in the layout of construction objects, etc;
- in hydraulic engineering when designing wave energy absorbers, dams, down-waters, water conduits, etc;
- on transport when equipping motor vehicles, sea vessels and submarines with devices and communications protruding above the object;
- in other spheres of human economic activity when arranging park zones, etc.

Another new direction of the Balabekov school is the use of vortex patterns in renewable energy sources. A very interesting fact is that the new direction of the Balabekov school, which originates from the work of Karman, was carried out at the Institute of General Mechanics RWTH Aachen University, which was once headed by Karman.

2. Description of the installation and experimental part

The installation was assembled from organic glass with dimensions of 1000x600 mm in the form of a square box (Fig. 1, a), attached to the corners on aluminum corners. Inside the unit, the plates are strung on vertical beams 1000 mm high and 20 mm in diameter. Plates measuring 70x50x0.2 mm from C-Steel (Fig. 1, b). The principle of operation of the installation: a stream of air is supplied from below, which, passing through the working area, drives the plate. The plates, making vibratory movements, generate electricity due to the installed piezoelectric elements on the plate.

Figure 1. Experimental setup with plates
The experimental work was carried out in the laboratory of the Institute of General Mechanics RWTH Aachen University. The essence of the work is to achieve a regime of simultaneous vortex formation to improve the performance of electricity generation with the same structural parameters of the installation and the same air flow rate. The study of the qualitative and quantitative parameters of the movement of the studied plates was determined using a Testo 477 stroboscopic tachometer; air flow velocity \( W_g = 4 \) m/s;

3. Results of the work

Studies of operating parameters, the influence of the design parameters of the plates, i.e. placement of plates in vertical and radial directions in the volume of the working area.

The results of experimental studies indicate that such structural parameters, the distance between the elements of the plates in the vertical and radial directions, has a great influence on the characteristics of the apparatus.

When flowing around the plates, vortices are formed alternately on one side of the element or on the other. Disruption of the vortices also occurs alternately and the vortex wake, in addition to the period of movement, also has a half-period. Therefore, for the plates, it is possible to achieve the regime of simultaneous vortex formation twice.

In violation of the in-phase mode in the operation of the plates, the performance decreases due to a decrease in the number of vortices formed in the volume of the working zone. This occurs as a result of the forced disruption of vortices, which did not complete the formation cycle behind bodies located upstream, vortices detached from bodies located downstream.

Studying the nature of the motion of the free ends of the vibrating plate in the setup showed that, due to the asymmetry of the vortex formation behind the plates, it affects the motion parameters \( \omega_{bp} \) and \( A \) significantly. So, on the curves \( \omega_{bp} = f(t_b/b) \) and \( A = f(t_b/b) \) (Fig. 2), in the modes of simultaneous vortex formation, at \( t_b/b = 2b \) and \( 4b \), the total power of the vortices is such that it is able to damp free vibrations ends of the plates.

However, the amplitude of the vibrations increases somewhat, since the component of the vortex force acts in correcting the movement of the free ends of the plates. Violation of the regimes of simultaneous vortex formation leads to the fact that the power of the vortices is not cumulative, and moreover, unformed vortices are disrupted during successive flow around the plates in the direction of gas flow. In this case, the vibration frequency increases, and the amplitude decreases.

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**Figure 2.** The dependence of the frequency and amplitude of vibration of the free ends of the plates on the vertical step between the plates
When the distance between the garlands with the plates of the elements changes in the radial direction \( tr \) (Fig. 3) in the mode of simultaneous vortex formation, a gradual decrease in \( \omega_v \) and a slight increase in \( A \).

Apparently, this is due to the mechanism of vortex formation, the frequency of which at \( tr/b < 2b \) is determined by the gap between adjacent elements, and at \( tr/b \geq 2b \) the width of the streamlined plates. The restructuring of the mechanism of vortex formation at \( tr/b > 2b \) leads to their insignificant effect on the parameters \( \omega_v \) and \( A \).

![Figure 3](image-url). The dependence of the frequency and amplitude of vibration of the free ends of the plates on the radial step

4. Conclusion

The work presents a new apparatus for converting the kinetic energy of the air flow by means of vibration of the plates of conversion into electrical energy. An experimental setup was designed and experimental work was carried out. The optimal values of the distances of the plates between themselves in the vertical and radial direction are determined. The mechanisms of interaction of vortex flows in the working area are described. As a result of the simultaneous vortex formation regime, the installation efficiency increases, as a result of which the generated energy increases.

This design is applicable in almost all industries, because it is possible to use the exhaust gaps, ventilation of the building and the wind itself in an open area. Of course, at the moment, the generation of electricity by means of piezoelectric elements is small, but the installation features mobility and ease of construction with minimal cost. The ability to use as an auxiliary source of energy for low-cost energy consumers such as sensors, lighting, maintaining an Internet connection, etc.

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