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Perspective morphing-based technology of improvement the aerodynamic properties of wind turbine blades

The perspective concept of morphing wind turbine blades was considered and revised. Different types of wind turbine morphing for reduction of stresses in the blade and improvement the blade aerodynamic characteristics were analyzed. The new idea of making the wind turbine blade of composite structure with stiff leading edge and flexible middle and tail parts of the blade was proposed and justified.

Wind power generation is a rapidly developing area in the modern energetic system to effectively minimize the consumption of natural non-renewable energy sources. Many countries of the world focus their special attention on developing this promising direction.

Nowadays, traditional bladed wind wheels with a horizontal axis of rotation have found the widest application in the world. But they are quite expensive and unsafe for the environment. That is why it is currently important to develop wind power generators of alternative structures. Among them there are wind power generators with a variety of blade shapes or wind power generators with a vertical axis of rotation of the rotor. Because of different reasons known alternative wind power generators are much less universal and energy efficient.

Under these circumstances, it would be reasonable to improve aerodynamic characteristics of the wind wheel blade by means of shape morphing of the blade to increase the amount of wind energy and to make this technology more energy-perfect.

As it is known morphing of the wind turbine blades can improve the power efficiency by changing their shape according to variations in wind speed [1]. Besides, they have the potential to markedly relieve non-desirable stresses in the blades to prolong their life while the wind is very strong.

Morphing of the wind turbine blades can be either “passive” or “active”. The passive morphing is applied to essentially monolithic blades and is based on the flexibility of their structure or, on elastic deformations. In contrast, “active morphing blades” allow to change blade aerodynamic characteristics through structural shape changes including span-wise change, chord-wise change, sweep change and twist change.

Morphing technologies are currently receiving significant interest because of their potential high aerodynamic efficiency, simple construction and low weight. However, for actuator forces to be kept low, a compliant structure is needed. This is in apparent contradiction to the requirement for the blade to be load carrying and stiff. This highlights the key challenge for morphing structures in replacing the stiff and strong design of wind turbine blades with more compliant structures [2].

The ideal material for a morphing structure must meet three conflicting requirements: load-carrying capability, deformability and low weight. As it is reported in [3] elastomeric and anisotropic materials have substantial potential for morphing on aircraft wings and wind turbine blades.

Improvement of aerodynamic characteristics of the wind turbine blades can be realized by means of modernization of its surface shape and mainly the blade leading edge, which will provide generation of a regular structure of longitudinal vortices and modification of streamlined surface structure to achieve increasing the angles of attack range when flow is unseparated.

The proposed problem of modeling the effect on the flow characteristics of the modified geometry leading edge is a special case of artificial vortex generation. This effect was studied in details for a number of cases of vortex generation. The first broad generalization of different methods of vortex generation on streamlined surfaces was undertaken by P. Chang in 3-volume edition "Separation of flow" [4].

The main disadvantages of artificial vortex generation technology include the additional energy losses associated with vortex generation, which significantly limits the possibility of its practical application. However, it is known some natural examples of streamlined surface vortex generators implementation. One of the most obvious is the complicated geometry of the shark skin (Fig.1). In addition, the technology of artificial vortex generation is regularly used in aviation. For example, a single vortex generator can be mounted on engine nacelles (Fig.2), as well as a system of small vortex generators is mounted on the wing upper surface of an airplane Boing 737.

Fig.1. Shark skin structure

Fig.2. Vortex generators mounted on engine nacelles

The vortex generation of modified geometry leading edge has a natural realization on the fins of humpback whales (Fig.3). This allows for the whale fins to remain effective during sudden maneuvers, and accordingly, at high angles of attack. From a technical point of view, this modification of the leading edge may be considered as intelligent vortex generator, since it is free of the total lack of vortex generators associated with the inevitable loss of energy. This type of vortex generation practically does not change the aerodynamic characteristics at the operational range of angles of attack. But it will be effective only for angles of attack at which flow separation occurs for airfoils without modification of the leading edge. This property has been studied in detail in the design of the wing of the Soviet Union aircraft Ilyushin - 62 (Fig.4) and confirmed its performance by its

Fig.3. Fins of humpback whale

Fig.4. Aircraft Ilyushin - 62 with single vortex generator on the wings

long-term operation despite of the fact that the single vortex generator was applied at the leading edge of the airplane.

It is known facts about successful attempts of direct copying fin geometry on the leading edge of the wind turbine blades [5], (Fig.5) as well as on the lifting surfaces of aircraft [5, 6], (Fig.6). As a result of this modification it would be possible to increase the angle of attack of unseparated flow of up to 40 degrees and to improve the energetic characteristics of the aerodynamic surfaces of up to 20%.

Thus, the wind turbine blade should have quite stiff construction to locate vortex generators at the leading edge of the blade for improvement aerodynamic characteristics. On the other hand, it should have compliant structure to reduce non-desirable stresses in the blades and prolong their life when the wind is strong.

The objective of these researches is to consider possibility of superposition which consists of making the wind turbine blade of composite structure, in particular, the leading edge of the blade is stiff to locate vortex generators, protuberances, and the middle and tail parts of the blade are flexible and made of elastomeric and anisotropic materials.

This superposition has the bionic justification because it corresponds to the implementation of the fins of a number of fish and bird wings. Besides this superposition allows to obtain interaction of regular in space longitudinal vortex systems formed from the leading edge protuberances with regular in time lateral

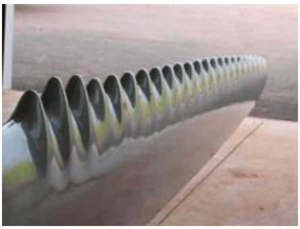

Fig.5. Wave shaped leading edge of the wind wheel blades

Fig.6. Vortex generators on the lifting surfaces of aircraft

vortices, forming behind the blade due to separation phenomena under highly loaded modes and at rough air.

Theoretical justification of the proposed superposition can be formulated in the following way. The elasticity of the blade profile will reduce the lateral vortex structures, reducing the hysteresis of the aerodynamic loads under periodic loads which usually act on the blades (both of traditional and atypical geometries); this effect is effectively and widely applied by waterfowl and birds. But in addition to this mechanism, which is well understood and studied, the leading edge with protuberances has no effect on the flow at angles of attack of the flow without separation but at big angles of attack the leading edge with protuberances forms an additional spatial regular structure in the form of an array of pairs of oppositely rotating longitudinal vortices at the downwind part of the blade (where separation of the boundary layer can occur). This longitudinal vortex structure modifies the boundary layer, increasing its spatiality near the streamlined surface, which, as is known, prolongs the flow separation and significantly reduces the negative effect of the separation phenomenon (the two-dimensional separation is always stronger and develops faster than the three-dimensional separation). These effects have natural realizations, but they are much more selective in nature, which is probably related to the synergy of the two effects under discussion, which, apparently, is positive only in a certain range of flow conditions.

Conclusion

Such interactions have not been studied so far, which justifies the scientific relevance of this area of research, whereas practical relevance lies in the purposeful use of the mentioned above interaction potential to create highly loaded blade systems of perspective wind generators. This interaction is the subject of current theoretical and experimental researches of authors. The results of which will be presented and analyzed in the report. The obtained aerodynamic characteristics of harmonically oscillating straight wing having wave shaped leading edge together with elastic middle and tail parts demonstrate generating the complicated unstable vortical structure, dependent on the frequency of oscillations and strong non-linear interaction between lateral and longitudinal vortical systems. The mechanism of this interaction and its optimal modes require deeper study and analysis, that will be the next step of authors efforts application.

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