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A. Mazurenko, DSc, Prof.,
V. Kravchenko, DSc, Prof.,
G. Luzhanska, PhD, Assoc. Prof.,
V. Shavrov,
V. Stanislavov
Odessa Polytechnic National University, 1 Shevchenko Ave., Odesa, Ukraine, 65044; e-mail: luzhanska@op.edu.ua

FEATURES OF THE BOUNDARY LAYER ORGANIZATION IN TESLA DISC TURBINES

А. Мазуренко, В. Кравченко Г. Лужанська, В. Шавров, В. Станіславов. **Особливості організації течії примежового шару в міждисковому просторі турбін Tesla.** Для забезпечення максимальної ефективності безлопаткових турбін типу Тесла важливо забезпечити ламінарний режим течії в примежовому шарі, що виникає на поверхні дисків. В залежності від режиму течії, стану поверхонь дисків та геометрії міждискових щілин змінюється характер примежового шару. Важливо, щоб режим його течії зберігався ламінарним, а відстань між дисками повинна бути не більше здвоєної товщину примежового шару. Для визначення параметрів, які необхідні для забезпечення максимальної економічності пропонується використати експериментальні дослідження характеристик прикордонного шару при обтіканні турбінних лопаток, які були проведенні на аеродинамічному стенді, який забезпечував рівномірне поле швидкості спрямленого потоку з мінімальною турбулентністю (0,7 %) в діапазоні швидкостей до 0,33 Маха. В цих дослідженнях важливим було визначення місця перехідної зони течії в примежевому шарі, що дозволяє дослідити умови стійкого підтримання та характеристики саме ламінарної течії. Зона перехідної області визначалась в експериментах по характеру зміни дотичної напруги тертя. Отримані результати дозволили встановити необхідні розміри міждискових щілин та кращі з точки зору режиму течії значення критерію подібності Re. Для гладкої поверхні ламінарний характер течії в примежовому шарі зберігається ламінарним на відстані від початку поверхні до відносної координати $\bar{x} = 0{,}17$ в досить широкому діапазоні числа Рейнольдса. Для шорсткої поверхні при Re=3,6·10^5 протяжність зони з ламінарним примежовим шаром приблизно така ж як і для гладкої поверхні. Однак, при Re=7,4·10^5 ламінарний характер течії закінчується дещо раніше – при $\bar{x} = 0{,}13$ з дуже короткою перехідною зоною між ламінарним та турбулентним характером течії. Товщина примежового шару при ламінарному обтіканні гладкої поверхні становить 0,5…0,7 мм, а для шорсткої поверхні дещо більше – 0,7…0,8 мм. Тобто, для забезпечення високої економічності дискових турбін типу Тесла відстань між дисками повинна бути на рівні 1…1, 5 мм.

Ключові слова: мікротурбіна, турбіна Тесла, примежовий шар, ламінарний режим

A. Mazurenko, V. Kravchenko, G. Luzhanska, V. Shavrov, V. Stanislavov. **Features of the Boundary Layer Organization in Tesla Disc Turbines.** To ensure maximum efficiency of bladeless Tesla turbines, it is important to maintain a laminar flow regime within the boundary layer that forms on the disc surfaces. Depending on the flow regime, the state of the disc surfaces, and the geometry of the inter-disk gaps, the nature of the boundary layer varies. It is crucial for the flow regime to remain laminar, and the distance between the discs should not exceed twice the thickness of the boundary layer. Experimental investigations of the characteristics of the boundary layer during the flow around turbine blades were proposed to determine the parameters necessary for achieving maximum efficiency. These experiments were conducted in an aerodynamic test rig that provided a uniform velocity field with minimal turbulence (0.7 %) within a speed range up to 0.33 Mach. The primary focus of these studies was to determine the location of the transition zone within the boundary layer, which allows for the examination of conditions for stable maintenance and characteristics of laminar flow. The transition zone was determined based on changes in the tangential friction stress in the experiments. The obtained results facilitated the establishment of the necessary dimensions for the inter-disk gaps and the optimum values of the similarity criterion Re from the perspective of flow regime. For a smooth surface, laminar flow within the boundary layer is maintained up to a relative coordinate of $\bar{x} = 0.17$ from the start of the surface, across a wide range of Reynolds numbers. For a rough surface, the extent of the zone with a laminar boundary layer is approximately the same as that for a smooth surface at Re=3.6·10^5. However, at Re=7.4·10^5 the laminar flow terminates slightly earlier, at $\bar{x} = 0.13$, with a very short transitional zone between laminar and turbulent flow characteristics. The thickness of the laminar boundary layer on a smooth surface is 0.5…0.7 mm, while for a rough surface, it is slightly greater at 0.7…0.8 mm. Therefore, to ensure high efficiency of Tesla disc turbines, the distance between the discs should be maintained at 1…1.5 mm, considering the requirements for laminar flow.

Keywords: microturbine, Tesla turbine, boundary layer, laminar regime

Introduction

Tesla turbines have been known for more than 100 years, but they have not found widespread use due to their relatively small power, which is limited to tens, or at best, hundreds of kilowatts. However, at the same time, their high efficiency of converting the potential and internal energy of the working body of steam or gas into work is noted [1 – 4]. The high efficiency is explained by the fact that the conversion and transfer of energy is carried out within the framework of the boundary layer on flat disks. At the same time, if a laminar flow regime is ensured in the boundary layer on the disks, there are no vortices that cause corresponding losses. Another important feature of such turbines is that the energy conversion does not take place on the blade devices, but in the region of the boundary layer in the space between individual flat disks, the total number of which can be significant [5, 6]. This means that wet steam can be efficiently used in such turbines without fear of wet steam erosion, as is the case

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in traditional steam turbines. Naturally, the small power of such turbines limits their use in large power generation, but it makes them quite promising in low-power cogeneration plants [3, 7, 8, 9], drive systems for backup power supply of boiler houses with steam boilers, for driving heat pump heating or cooling systems, as well as for power generation in emergency situations at large units of thermal or nuclear power plants.

Analysis of the latest research

Figure 1 shows a simplified design diagram of a bladeless (or disk) turbine known as a Tesla turbine [4]. The working medium (steam or gas) is fed from the nozzle into the gaps between the disks, and then, moving in these gaps along a spiral trajectory, it is discharged from the turbine in the central part to the outside (into the condenser, heat exchanger, or even into the atmosphere) [5, 10 – 14]. To ensure the high efficiency of such a turbine, the size of the gap between the discs, as well as the flow regime in the boundary layer, is of great importance. The gap between the disks should not exceed the total thickness of the boundary layers of the two disks, and the flow regime in the boundary layers should be laminar [12].

Goal

The purpose of the work is to study the operation of the Tesla disc turbine and create a highly economical bladeless microturbine for use in energy supply systems, as well as for power generation in emergencies of power facilities.

Presenting main material

To determine the parameters that are necessary to ensure maximum efficiency, it is proposed to use experimental studies of the characteristics of the boundary layer when flowing around turbine blades. Research was carried out at the Odessa Polytechnic in the 1980s on an aerodynamic stand with a capacity of 150 kW [15], which provided a uniform velocity field of a directed flow with minimal turbulence (0.7 %) in the speed range up to Mach 0.33.

In these studies, it was important to determine the place of the transition zone of the flow in the boundary layer, which will allow studying the characteristics of the laminar flow itself. The zone of the transition region was determined in experiments by the nature of the change in the tangential friction stress τ. The value of τ can be determined from the integral equation of impulses [6]:

$$\frac{d\delta^{**}}{dx}+\delta^{**}\left[\frac{1}{\rho_0\cdot U^2}\cdot\frac{d(\rho_0\cdot U^2)}{dx}+\frac{H}{U}\cdot\frac{dU}{dx}\right]=\frac{\tau}{\rho_0\cdot U^2}, \quad (1)$$

where δ^{**} – conventional thickness of momentum loss:

$$\delta^{**}=\int_0^{\delta}\left(1-\frac{u}{U}\right)\cdot\frac{u}{U}dy; \quad (2)$$

δ – boundary layer thickness;

u – the flow velocity inside the boundary layer at a distance y from the surface;

U – flow velocity at the outer boundary of the boundary layer;

ρ_0 – flux density at the outer boundary of the boundary layer;

x – distance from the beginning of the surface covered by the stream.

For a non-compressible working environment with $\rho = \text{const}$ we get:

$$\frac{d\delta^{**}}{dx}+\delta^{**}\frac{dU}{U\cdot dx}(2+H)=\frac{\tau}{\rho_0\cdot U^2}, \quad (3)$$

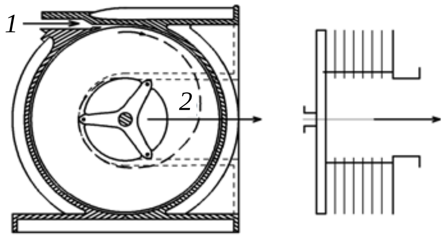
where H – form parameter of the boundary layer,

$$H=\frac{\delta^{*}}{\delta^{**}}, \quad (4)$$

δ^{*} – conditional thickness of flow displacement,

$$\delta^{*}=\int_0^{\delta}\left(1-\frac{u}{U}\right)\cdot dy. \quad (5)$$

In experimental studies of the character of flow around surfaces and determination of τ, micrometric probes with the thickness of the receiving part of 0.1 mm and 0.18 mm were used on the aerodynamic bench to establish the character of the velocity distribution in the boundary layer. A photograph under a microscope of a 0.1 mm probe is shown in Fig. 2 compared to a 5-channel probe with a receiving head diameter of 3 mm.



a *b*

Fig. 1. Scheme of the Tesla disk turbine: *a* – side view; *b* – disks in section; *1* – steam inlet to the nozzle; *2* – steam

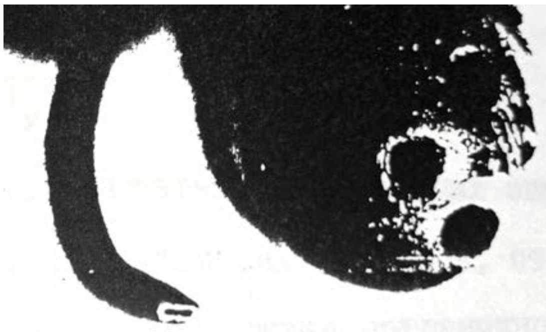


Fig. 2. View of a microprobe with a receiving part of 0.1 mm and a 5-channel probe with a head diameter of 3 mm

The use of such probes made it possible to penetrate relatively deeply into the boundary layer of the surface with a length of *X* of about 150 mm. The graph of the speed of movement in the boundary boundary layer at relative distances of $\overline{x} = x/X$ in the range from 0.04 to 0.95 from the beginning of the surface was built in coordinates u/U and y, where y is the distance from the surface. The value of u/U was determined by the simplified formula $u/U = \sqrt{(P_f - P)/((P_f - P)_{y=\delta})}$, since at $M < 0.4$ the working medium can be considered incompressible. Here P_f is the total pressure at this point of the boundary layer, and *P* is the static pressure.

Fig. 3 shows velocity plots in the boundary layer for the cases of an aerodynamically smooth surface and a surface with a relative roughness of $\overline{k} = 0.5 \cdot 10^{-3}$ and for flow regimes with Reynolds numbers $\mathrm{Re} = 3.6 \cdot 10^5$ and $\mathrm{Re} = 7.4 \cdot 10^5$.

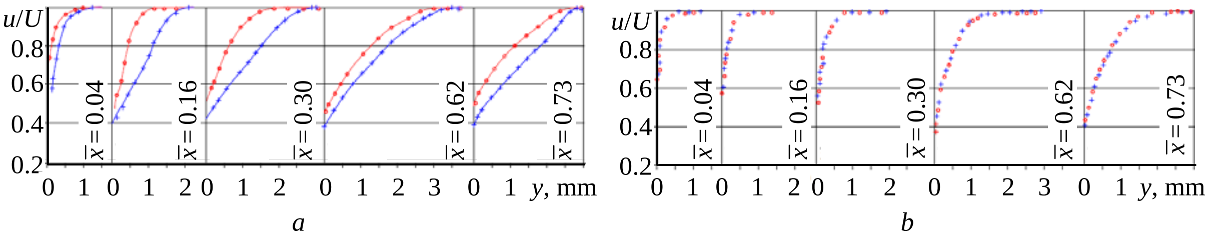


Fig. 3. Velocity plots in the boundary layer on the surface with *x* coordinate and flow modes with: at $\mathrm{Re} = 3.6 \cdot 10^5$ (o); at $\mathrm{Re} = 7.4 \cdot 10^5$ (+); *a* – surface roughness $\overline{k} = 0.5 \cdot 10^{-3}$; *b* – smooth surface

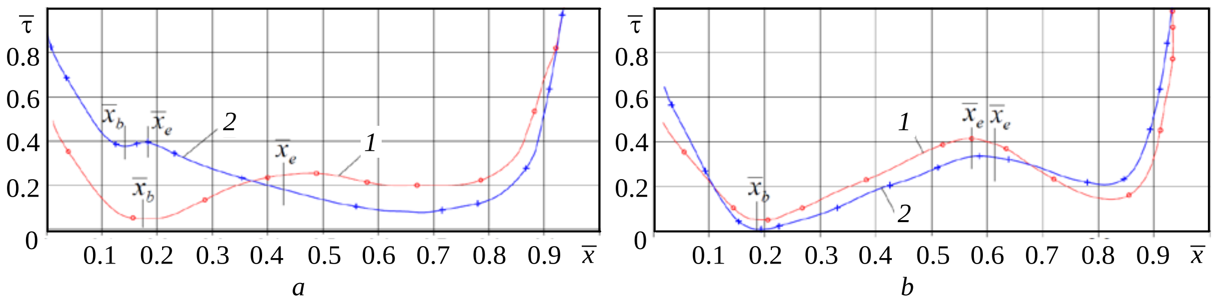


Fig. 4. Determination of the laminar flow zone in the boundary layer: *1* – at $\mathrm{Re}=3.6 \cdot 10^{5}$ 0; *2* – at $\mathrm{Re}=7.4 \cdot 10^5$; *a* – surface roughness $\overline{k} = 0.5 \cdot 10^{-3}$; *b* – smooth surface; $\overline{x}_b$ – the beginning of the transition region, $\overline{x}_e$ – the end of the transition region

The results

According to the results of the experimental determination of the characteristics of the boundary layer and the method of determining the tangential stresses given above, in Fig. 4 shows the graphs of

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changes in the relative value of the frictional tangential stress $\overline{\tau}$ at different distances from the beginning of the surface flowing around the stream under the specified conditions.

Analyzing the results shown in Fig. 3 and Fig. 4 the following can be noted for different surfaces.

For a smooth surface, the laminar nature of the flow in the boundary layer remains laminar at a distance from the beginning of the surface up to $\overline{x} = 0.17$ in a fairly wide range of Reynolds number.

For a rough surface at $\mathrm{Re} = 3.6 \cdot 10^5$, the length of the zone with a laminar boundary layer is approximately the same as for a smooth surface. However, at $\mathrm{Re} = 7.4 \cdot 10^5$, the laminar nature of the flow ends earlier $\overline{x} = 0.13$ with a very short transition zone between the laminar and turbulent nature of the flow. The thickness of the boundary layer during laminar flow around a smooth surface is 0.5...0.7 mm, and for a rough surface it is slightly more – 0.7...0.8 mm.

Conclusions

In the work, studies of the Tesla disk microturbine for generation and power supply systems have been carried out. Analyzing the obtained results of the performed experiment, the following were determined:

– places of the transition zone of the flow in the boundary layer, which allows to study the conditions of stable maintenance and characteristics of the laminar flow itself;

– the required sizes of the inter-disc gaps and the best from the point of view of the flow regime, the value of the similarity criterion Re: for a smooth surface, the laminar character of the flow in the boundary layer remains laminar at the distance from the beginning of the surface to the relative coordinate $\overline{x} = 0.17$, and for a rough surface – at $\overline{x} = 0.13$ with a very short transition zone between the laminar and turbulent character of the flow; while the value of Re changes and is equal to $\mathrm{Re} = 3.6 \cdot 10^5$ and $\mathrm{Re} = 7.4 \cdot 10^5$;

– with laminar flow, the most appropriate thickness of the boundary layer was found, which is 0.5...0.8 mm for a smooth surface and 0.7...0.8 mm for a rough surface, with a relative roughness of $\overline{k} = 0.5 \cdot 10^{-3}$.

The results obtained in the course of the conducted research indicate that to ensure high efficiency of operation of a bladeless disk microturbine of the Tesla type, the distance between the disks should be at the level of 1…1.5 mm.

In addition, the use of disks with minimal roughness in the design of the Tesla microturbine is very important, as well as the experimentally determined advantages of operating modes.

The use of disk microturbines of this type will allow to significantly improve the operation of energy systems, increasing their technical and economic indicators.

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Мазуренко Антон Станіславович; Anton Mazurenko, ORCID: http://orcid.org/0000-0002-0165-3826
Кравченко Володимир Петрович; Volodymyr Kravchenko, ORCID: http://orcid.org/0000-0002-7557-3327
Лужанська Ганна Вікторівна; Ganna. Luzhanska, ORCID: https://orcid.org/0000-0002-3784-5926
Шавров Віктор Вікторович; Viktor Shavrov, ORCID: https://orcid.org/0009-0006-1023-0725
Станіславов Володимир Дмитрович; Volodymyr Stanislavov, ORCID: https://orcid.org/0009-0002-4512-2725

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