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Analysis of the Current Development of Tidal Energy Turbines with Bionic Blades

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Abstract: Tidal energy is mainly used to generate electricity, and the principle is that the turbine blades rotate under the impact of the tide, which in turn generates electricity. The blade is the core component of a tidal turbine and determines the efficiency of tidal energy capture. In order to make tidal turbines more efficient, researchers have focused on the design of the blade. With the rise of bionics in recent years, the design of bionic blades has become a hot topic of interest for many researchers. This paper briefly describes the development status of tidal turbines and the development status of tidal turbines with bionic blades, summarises the problems that exist in the development of tidal turbines with bionic blades, and puts forward suggestions for the current situation.

1. Introduction

Tidal energy is a type of ocean energy, which is the kinetic energy of seawater flow due to the gravitational force of the sun and the moon. Compared to wave energy and ocean tidal energy, tidal energy has certain regularity and predictability, and has the advantages of high availability and low environmental impact[1]. According to a report by Atlantis Energy, tidal energy has a global storage capacity of over 120 GW[2]. In recent years, many countries have carried out research on tidal wave energy generation technology and established various tidal wave energy generation devices, and tidal wave energy turbine generation devices have been rapidly developed worldwide and have achieved certain results. The turbine is the main device for tidal energy capture, which converts ocean energy into mechanical energy and then into electrical energy[3], but the current efficiency of the turbine is low, and it is difficult to meet the power supply needs of tidal power stations. As the core component of the tidal energy capture device, the performance of the blade plays a decisive role in the energy harvesting efficiency of the turbine.

With the rise of bionics, tidal energy turbines with bionic blades have also received widespread attention. By studying the hydrodynamic characteristics of typical fish fin configurations, extracting the configuration parameters affecting the movement efficiency of fins in water, and combining them with turbine blade design, a tidal energy turbine with bionic blades has been formed, and compared with traditional blade turbines, the energy conversion efficiency of bionic blade turbines has been significantly improved[4]. The researchers have demonstrated the working principle of the bionic blade turbine under real sea conditions through numerical simulations and model tests, revealing the important role of bionics in the design of tidal turbines.

2. Current Energy Development

Although mankind's knowledge and use of ocean energy is relatively early, the development and use of tidal wave energy only slowly began to develop in the 1970s[5-6].The first country to investigate tidal wave energy was the United States. From 1973 to 1976, in just three years, the US research team designed an energy converter for low-speed currents based on the design principles of hydraulic turbines; however, due to the backward technology at that time, the low efficiency of hydraulic turbines and the harsh working environment in the ocean, the development and utilisation of tidal current energy entered a slow period until after 2000, due to the shortage of non-renewable energy sources and the lack of renewable energy on the earth.The shortage of renewable energy and the destruction of the earth's ecological environment and other problems, various countries in the world have to strengthen the development and use of new energy, countries began to tidal energy and other projects to invest a large number of funds and researchers, the purpose is to solve the energy crisis as soon as possible, the development of new energy. At present, the countries with more research on the development of tidal wave energy technology include the UK, the USA, Russia, China and Australia.

2.1. Current Status of Research on Tidal Energy Turbines

Similarly to wind turbines, tidal energy generation uses the flow of a fluid to rotate the blades to generate kinetic energy, which is then converted into electricity. Because seawater is subject to the gravitational pull of the sun and moon, tidal energy is not only regular but also highly stable. At the same flow rate, tidal energy can generate 800 times more electricity than a wind turbine. In contrast to wind turbines which are installed in the air, tidal current energy generators can be installed either in seawater or on the bottom of floats on the water.

The United States was the first to propose tidal power generation in the Florida Sea, with a Coriolis tube turbine placed 30m underwater and with a 110m long unit and a current speed of 2.3m/s, producing 83MW[7].In 2003, the UK made a breakthrough in tidal power generation with the development and design of a large horizontal axis tidal power generator by MCT with a 5.5m radius turbine blade and a 300KW two-bladed horizontal axis generator set, the "SeaFlow ", as shown in Figure 1 below. This was followed by the development of the first commercially available tidal current turbine, the "SeaGen", which has generated in excess of approximately 1.986 MW. In 2011 Scotreneables in the UK completed the SR2000 turbine set tidal power generator, which weighs 550 tonnes and generates 2MW of power[8].The 250 kW Open Centre tidal turbine was developed by OpenHdro in Ireland and added to its national grid[9].The Norwegian tidal power station at Kvlsund was tested with a model unit and started operation in 2009, and a 1MW tidal power installation was installed and commissioned in 2010[10].The French tidal power demonstration project "Paimpol-Brehat", shown in Figure 2 below, is the world's first grid-connected tidal array installation since the turn of the century and uses cables to deliver electricity to the French island of Ushant[11].In February 2019, a long period of research and design by Magallanes Renovables, Spain, resulted in the design of Spain's proudest tidal power generator, the ATIR tidal power generator, shown in Figure 3 below. The plant was installed and connected to the grid at Fall of Warness and delivered electricity to the UK National Grid for the first time. In late 2018, a project to develop tidal wave energy generators was co-funded by the US Department of Energy and the New York Energy Research and Development Authority, and in April 2019, Verdant Power successfully developed a new fifth generation of tidal wave energy units based on previous generations of tidal wave energy generators, with data aggregation, structural improvements and more, as shown in Figure 4 below. This project is planned to be a commercial demonstration project and commercialised by 2020.

Figure1:"SeaFlow "Trend Energy Equipment.

Figure2:"Paimpol-Brehat"Trend Energy Equipment.

Figure3: Spain ATIR tidal energy equipment.

Figure4: U.S. 5th generation tidal.

Up to now, China has made great progress in the development of design methods, key technologies and testing devices for tidal energy conversion power generation systems. Harbin Engineering University, Zhejiang University and China Ocean University have developed various prototypes of vertical shaft and horizontal shaft type 100W-600kW as well as floating type and sitting-bottom gravity type fixed technologies and accumulated experience in sea trials. Since 1982, Harbin Engineering University has developed vertical and horizontal shaft type, floating and sitting bottom type, sitting bottom type double rotor vertical shaft straight blade variable pitch turbine "Wanxiang No.2", installed electric control system above the coast, and independent power supply to the lighthouse from the sea range transmission. Figure 5 shows "Haiming I", the design power of this equipment is 10kW, the use of sitting bottom horizontal axis fixed pitch impeller direct drive generator scheme, three legs base support a frame and hydro generator set, with 2.0m/s and 2.3m/s flow rate, to achieve power generation 10kW, system efficiency 78% and 34.5%.The "Sea Energy I" shown in Figure 6 is a 100 kW tidal power plant designed by Harbin Engineering University. The plant adopts the university's self-developed double-unit tidal power generation device with a total capacity of 300 kW and the floating vertical shaft turbine tidal power generation technology. The "Sea Energy II" shown in Figure 7 adopts the floating horizontal shaft impeller direct-drive low-speed generator technology, the carrier is fixed to the seabed by four sets of highly elastic mooring system, and two two two-bladed horizontal shaft paddle turbine generator sets are installed at the lower end of the two columns, the impeller diameter is 12m, the blade variable paddle control adapts to the bi-directional tide, the impeller direct-drive ultra-low-speed The "Sea Energy III", shown in Figure 8, adopts a floating vertical shaft cross-type impeller driven by a speed increaser, and the carrier is fixed to the seabed by four highly elastic mooring systems, with two hydro-generators, impeller diameter 6m, generator speed 350rpm, design rated current speed 3.0m/s.

Figure5: "Haiming I" Trend Energy Equipment.

Figure6: "Sea Energy I".

Figure7: "Sea Energy II ".

Figure8: "Sea Energy III ".

In recent years, tidal power technology has been developing rapidly, but most of it is still at the demonstration research stage, and some of it is even at the conceptual design stage. Most of the research projects on tidal power generation have a capacity of white watts or kilowatts, and most of them are at the experimental research stage or limited to universities, and are not commercially available. In addition, the installation of tidal power plants in water requires the solution of a number of technical problems, such as the design of turbines to capture tidal energy, the installation and maintenance of power plants, the transport of electricity and the corrosion protection of power plants.

2.2. Current Status of Development of Bionic Blade Tidal Energy Turbines

It has been shown that applying the natural features of organisms such as birds to the design of horizontal axis wind turbine blades can significantly improve the efficiency of generators, so whether applying them to turbine blades can improve the efficiency of turbines. British scholars Batten[12]and Bahaj[13]and others believe that there are differences in the nature of water turbines and wind turbines, and there is still doubt whether the methods used to design wind turbines can be used to design water turbines. In order to solve this problem they follow the design method of wind turbine blades to design horizontal axis water turbine blades and then verify them through experiments, and the final results show that the design of wind turbine blades The final results show that the method and theory of designing wind turbine blades can be applied to the design of turbine blades, and the validation provides strong proof of the validity of the theoretical approach to turbines.

In 2014, Rongkang Di Gao of Ocean University of China took the black-printed shark as the research object, as shown in Figure 9, and established a three-dimensional digital model of the shark fin, so as to obtain a bionic model of the horizontal axis tidal energy turbine blade, and then carried out hydrodynamic numerical simulation analysis of the bionic blade. The experimental results show that in the low tip speed ratio range, the bionic blade turbine can effectively improve the turbine energy efficiency and increase the power generation in certain working conditions, but the axial force also corresponds to an increase and the pressure distribution is unstable. In the actual engineering application, a comprehensive balance should be considered according to the demand[14].

Figure9: Tidal energy turbine power generation system with bionic shark tail fin.

In 2015, Gaozhen Di of Ocean University of China took the shark fin as the object of wing acquisition and obtained the conformational surfaces of the pectoral and caudal fins of the shark through 3D scanning, and then analyzed the performance of the turbine through numerical simulation. The experimental results show that the torque force to the rotating shaft of both the conventional blade and the bionic blade increases first and then decreases with the increase of the pitch angle under ideal conditions, and the pitch angle that reaches the maximum value is different, 70° for the bionic blade and 60° for the conventional combined blade, and when the two blades reach the maximum torque value, the bionic blade is slightly larger than the conventional combined blade, so the performance of the bionic blade is slightly better than that of the conventional combined blade; meanwhile, the performance of the bionic blade is compared with that of the conventional combined blade. At the same time, the flow field distribution of the turbine with several types of blades was compared, and the bionic blade was more beneficial to the efficiency improvement in both velocity field and pressure field[15].

In 2018, Qingzhao Liu from Dalian University of Technology took a bionic blade model with leading edge nodules as the research object, as shown in Figure 10, and investigated the effect of leading edge nodules on the hydrodynamic performance of the blade of a tidal energy turbine through flume model experiments. The experimental results show that when the incoming flow angle is less than 33°, the characteristic curves of lift coefficient, drag coefficient and lift-to-drag ratio of the bionic blade and the standard blade at four different Reynolds numbers have the same trend of change. In the stall zone, the maximum lift coefficient of the bionic blade increased by 14.09%, the maximum drag coefficient decreased by 30.28% and the maximum lift to drag ratio increased by 63.64%, which indicated that the hydrodynamic performance of the bionic blade with leading edge nodules was significantly better than that of the standard blade[4].

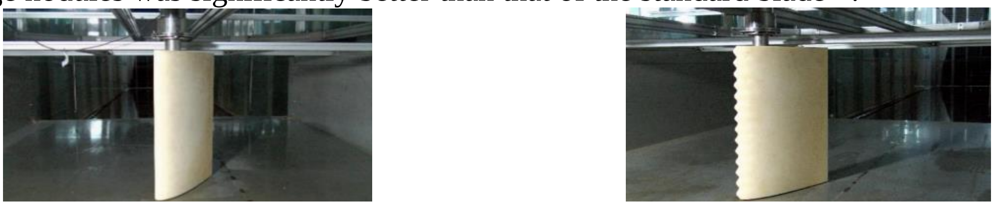

Figure10: Comparison of standard and bionic blade models.

In 2022, Liu Yan from Jiangsu University of Science and Technology conducted a numerical simulation of a bionic-bladed turbine using STAR-CCM+ in order to investigate the effect of bionic blades on the performance of the turbine, and compared the pressure and flow field characteristics with those of a conventional turbine to investigate the changes in the hydrodynamic characteristics of the bionic turbine and the conventional turbine under different operating conditions. The experimental results show that the bionic turbine mainly acts in the low tip speed ratio range while the blade stalls, and the performance improvement of the bionic turbine is less significant in the high tip speed ratio region. In addition, the leading edge nodules can produce larger torques and the bionic horizontal axis tidal energy turbine starts with lower flow rates. These research test methods and conclusions provide reference value and guidance for subsequent research on the application of bionics to tidal energy turbines[16].

3. Main Problems Facing Research on Bionic Blade Turbines

Although there has been some progress in bionics in the design of tidal energy turbines, and relevant data with high scientific value have been obtained, the research is still at the eve stage of technical research and industrialisation from the current technical development, and there are still many problems to be solved. There are mainly the following 3 aspects of performance.

1) The theory and development techniques for introducing bionics into the design of tidal energy turbines are still being explored, and researchers at home and abroad do not share a uniform view of bionic blade tidal energy turbine technology, and indeed unifying this view is not easy because the marine resources are not the same from country to country, and the

focus on tidal energy utilisation is not the same, making it difficult to arrive at a unified technology.

2) The current use of tidal energy is mainly through the force of the turbine blades to convert the kinetic energy contained in the movement of seawater into kinetic energy for the rotation of the turbine, after the turbine starts to rotate, the rotor of the generator is driven by mechanical devices to rotate, thereby outputting current.
3) From the published literature, the performance of the bionic blade tidal energy turbine is better than that of the conventional tidal energy turbine. Compared to the conventional tidal energy turbine, the key issues such as material properties, structural strength, stability, steadiness and technical maturity of the bionic blade turbine face tests and need to be further verified.

4. Countermeasures and Recommendations

4.1. Increase Policy Support

The state should introduce policies to encourage the research and development and utilisation of tidal wave turbines, make it clear that the relevant local governments provide the necessary premises and support for tidal wave turbine testing, and establish authoritative government-level tidal wave turbine research and development teams to provide support for the research and development of tidal wave turbines as far as possible.

4.2. Strengthen School-Enterprise Cooperation

A development system with government support and joint input from schools and enterprises should be formed to effectively bring into play their respective strengths and break the current dilemma caused by insufficient funding for research and development and technical bottlenecks. It is important to actively expand the idea of combining the characteristics of tidal wave energy turbines and bionic blades in order to achieve the goal of improving the efficiency of tidal wave energy turbines in gaining energy.

4.3. Technological Breakthroughs

Bionic blade tidal energy turbine to investigate should start from the leaf element design, the bionic technology and traditional leaf element momentum theory combined for the optimization of the turbine blade design, improve the bionic blade turbine structure strength, stability. In the design of tidal energy turbine blade shape, the better performance airfoil should be selected from more airfoil types, analogous design on the tidal energy turbine blade, which will have potential research significance to improve the energy gain efficiency of the turbine.

5. Concluding Remarks

This paper mainly reviews the development status of tidal turbines with bionic blades. The bionic blade tidal turbine is designed from a bionic perspective to optimise the blade design, applying the excellent hydrodynamic properties of marine organisms to the design of tidal turbine blades, which plays a positive role in improving the efficiency of tidal turbines and increasing the utilisation of tidal energy, and reveals the important application of bionics in engineering design, which has certain reference value for the development and promotion of marine energy.

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