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Hydrokinetische Turbinen in innovativen Systemlösungen zur ökologisch verträglichen Flussenergienutzung

Hydrokinetic turbines in innovative systems solutions by using the power of rivers in an environmentally sustainable way

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Abstract:

The paper gives a discussion and reflection of an innovative project on the hydrokinetic power production area. The realized project is part of „Wachstumskern Fluss-Strom Plus", (English translation: Expansion core River-Power-Plus). The project was government-funded by the German Federal Ministry of Education and Research. It was realized at the Merseburg University of Applied Sciences from July 2015 to July 2018. The project's title is „Fluid and Mechanical Engineering of the Hydrokinetic Turbines". Two different types of hydrokinetic turbine were developed, constructed and successfully tested. The tests were realized on the test *carrier VECTOR in the Elbe-Havel-Channel as well as at the reference place in the river Bode near the small location of Neugattersleben. Both locations offered realistic conditions for testing. Various computational fluid dynamics helped as an analyzing tool to model the fluid characteristics of the construction und realize optimization of the profile of running wheels and the floating body unit during the development process. Calculations of solidity by FEM were also carried out to guarantee the stability and reliability of the turbines. The constitutions of the turbines were made according to their location. Therefore comprehensive engine characteristics were theoretically developed and practically proved. The use of these engine characteristics during the development process helped to make the dimensions of the individual turbine aggregate short and user-friendly. The results were used to prepare a customer-specific production of type series of turbines with different power levels. The results of this scientific project were published and shared with all cooperation partners of the Network River-Power-Plus. They all gained the know-how to produce such hydrokinetic turbines with the characteristics of low speeds of flow velocity, low head of water and high volume flow rates. Six oral presentations and four expositions of students were published, which can be used by the national and international public. The activities are continued under the direction of ZPVP GmbH (Zentrum für Produkt-, Verfahrens- und Prozessinnovation Magdeburg). Questions and comments can be put forward at http://www.flussstrom.eu.*

Keywords: *renewable energy solution, decentralized electrification along rivers, hydrokinetic turbines for rivers;*

1. Introduction

This paper presents a project realized within the framework of a regional cooperation of 18 companies and 8 research institutions from Central and Northern Germany. This cooperation was supported by the funding program "Innovative Regional Growth Cores" of the Federal Ministry of Education and Research. The Regional Growth Core, called "River-Power Plus", is aimed at generating base-loadable energy from ecologically-compatible river hydropower units. The Alliance pursued research strategies and development tasks in six subprojects:

- energetic development of sites with low hydropower potential through economically-efficient and ecologically-compatible hydropower units, especially for free-flowing waters,
- continuous expansion of the capacity of the system solution for river energy applications according to the motto "the right solution and the right product or services for every (small) hydropower location".

In joint project 3: "Technology development for small hydroelectric engines", various hydroelectric power units were designed, constructed and tested in practice, which use the flow potential in rivers to generate electrical energy. The key characteristic of the new units was that they work economically even at low flow velocities and with small differences in the flow height. On the basis of various preliminary investigations, the task of the subproject 3.5 "Flow and machine technology of hydrokinetic turbines" described here focused on the development and optimization of two hydrokinetic turbines with different diameters and different numbers of blades. In cooperation with the subproject 3.6 "Production technology and construction of test patterns of hydrokinetic turbines (HKT)", the two prototypes were built by the company Formstaal GmbH & Co. KG Stralsund and tested under different conditions.

Hydro turbines have been used on a large scale since about 1750 [1] to drive equipment and machinery. The use of water wheels occurred much earlier and can be traced back to antiquity. Figure 1 depicts today's conventional hydropower machines with typical fields of application depending on the height of fall and the flow volume of the water.

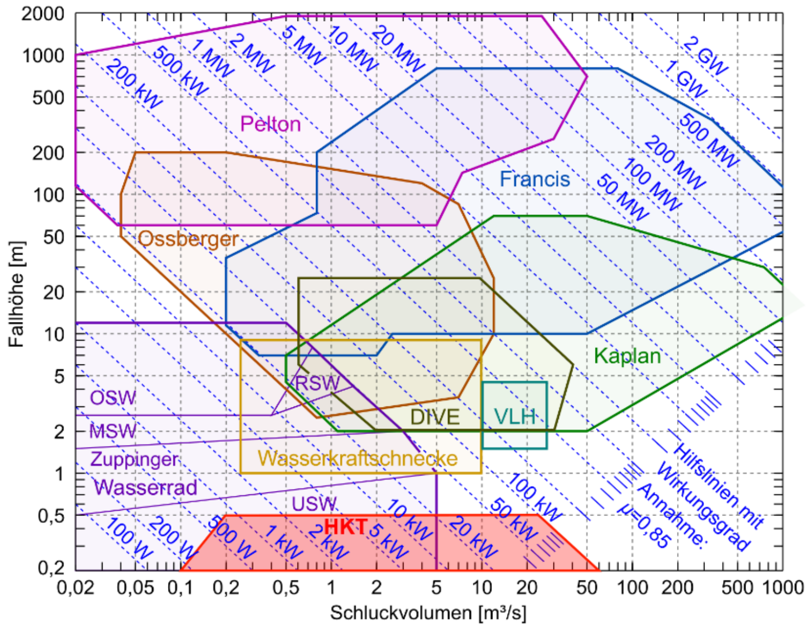

Figure 1 - Overview water turbine [2]

The centre of growth was aimed at systems that can be used cost-effectively in remote locations without a central energy supply. Here, in particular, the energy of rivers with low flow rates should be used without structural measures. Axial turbines with a high specific speed were investigated in the presented project. These hydrokinetic turbines (HKT) use the energy of running water, do not require a barrage, and are fish- and environmentally friendly. In Figure 1, the area of application is shown in red. In the last 15 years this concept has been taken up by different companies and research institutions.

Figure 2 - different solutions of hydrokinetic turbines - Twin-Turbine [4] (left), Hydro Green Energy [6] (center) and KSB AG [3] (right)

In 2012, for example, there were 5 different design proposals for hydrokinetic turbines worldwide, some of which are shown in Figure 2. Even low specific energies of the water in the order of Y = c_2 / 2 = 1.13 J / kg to 6.13 J / kg were intended for use. These, in combination with large volume flows, are abundantly available in many rivers both in Germany and throughout the world, and thus allow for a very large total power output. The task now was to develop and design the construction of water turbines which are able to decentralize these water potentials for a reasonable power output of P = 1.0 kW to 120 kW.

2. Method

As part of the project, two hydrokinetic turbines were designed, constructed and implemented as prototypes. They differ in size, number of vanes and frame construction. The first prototype has a casing to improve the flow of the impeller. This is designed in the shape of a nozzle and at the same time serves as a floating body due to its hollow chambers (Fig. 3). Two stabilizers are mounted on the top of the casing to hold the turbine straight and in the direction of the water

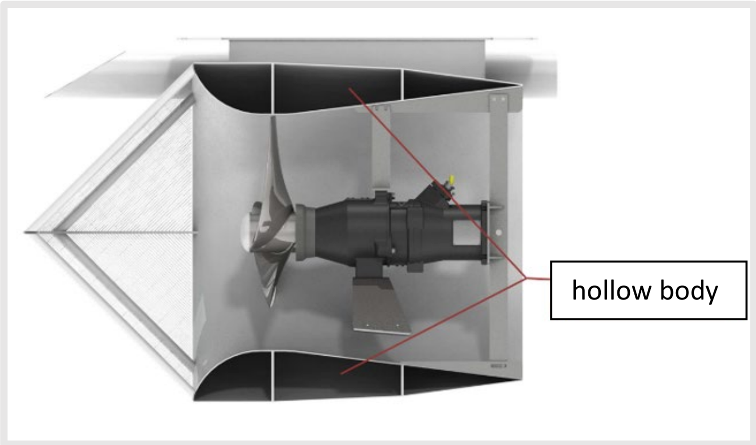

Figure 3 – Prototyp 1

flow. The impeller is located in the nozzle at the narrowest point and is attached to the generator, which is held in the casing by metal struts. The core of this hydrokinetic turbine is an axial impeller with three blades and a tip speed ratio of $\lambda = 3.3$. The first prototype's grate, for its own protection and for fish, was selected in cooperation with the Institute of Water Management, Urban Water Management and Ecology. The technical data of the turbine revealed that fish protection without a protective screen is not guaranteed. The guard wire has a mesh size of 10x10 mm and a setting angle of 45 °. This ensures sufficient flow and at the same time guarantees the protection of native animals. The flow difference before and after the installation of the protective grate was measured. For this purpose, flow sensors were installed outside the turbine and behind the grate, directly in front of the rotor blades. The difference was between 5 and 10 percent, depending on the flow velocity. The steep angle of attack of the protective structure allows fish to move unhindered from the grate and not be caught by the suction of the flow.

For the second prototype (Fig. 4 left) a design was created without turbine casing. By means of a morphological box the various sub-functions were broken down, and for each individual sub-function several solution variants were listed, initially independent of advantages and disadvantages. The possible combinations of the different subfunctions generated several different concepts. These were then qualified further to find one or more complete solutions.

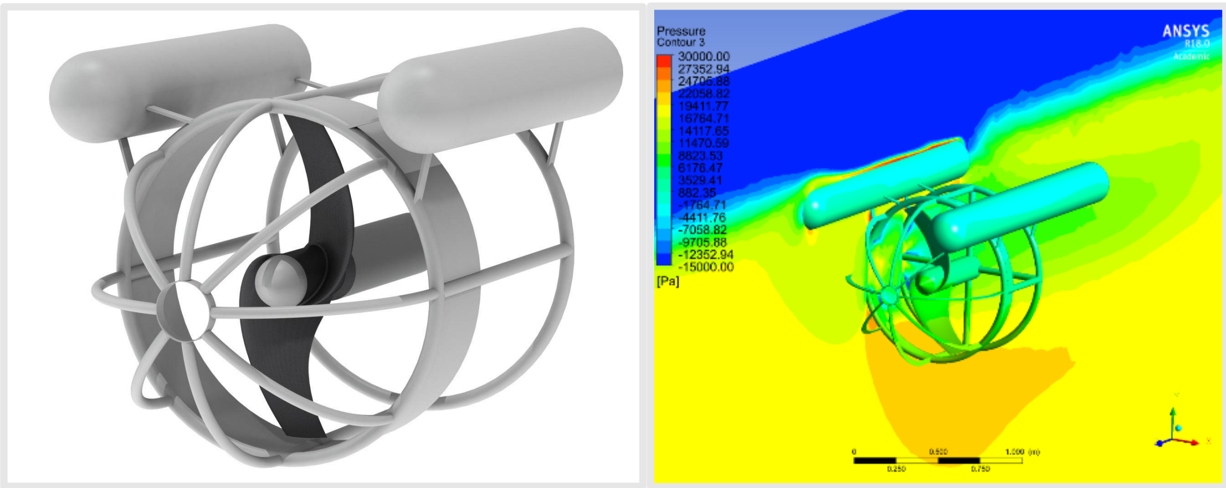

Figure 4 - Prototyp 2 (left) and CFD Prototyp 2 (right)

The potential solutions were analyzed by detailed CFD simulation (Fig. 4 right), and the best were selected. Furthermore, strength and stress calculations were performed for the turbine wheels. For the high-speed axial turbine with the low hub ratio of di / da = 147 mm / 900 mm = 0.163 and the strong blade twist, the profile NACA 4415 with the minimum glide ratio of ε = 0.017 to 0.065 is suitable. The two blades of the second prototype were each designed and constructed for 10 impeller cuts. In order to avoid the build-up of fibrous materials such as grass and other durable substances on the impeller, which can lead to blockages, the blades were bent in the direction of rotation to the rear. An identical procedure took place in the construction of the three-bladed impeller of the first prototype. The design of the second prototype gave a theoretical power of 418 W at a flow velocity of 1.5 m / s and a rotor speed of 120 rev / min. The frame or cage for the second prototype is made of individual round tube profiles. In the area of the impeller, a protective cloth is mounted around the frame, which is to protect the impeller from flotsam and / or damage from the side. The second prototype has two floats at the top which are offset by 45 ° from the central axis. On each of the floats there is a perforated plate with several holes for attaching the tethers of the turbine. Through the individual holes it is possible to vary the attachment point of the tethers and thus to change the trim of the turbine.

The flotsam grate runs forward and is tapered, and all struts are connected in the middle by a ring. This stops the incoming flow from being swirled too strongly at the point of intersection of the individual struts. On the basis of numerical flow and strength investigations combined, the startup behavior was investigated, as well as the change in flow velocities. It was concluded that the stresses on the material do not exceed the material's limits. The most critical point is at the transition from the rotor blade to the hub.

3. Results and Discussion

Both prototypes were built by the company Formstaal GmbH & Co. KG in Stralsund. The experiment and the recording of observations were carried out on the research trial vehicle VECTOR (Fig. 5). The VECTOR is an adaptive navigable test platform for basic research and experimental development of turbomachinery. The catamaran hull allows centralized installation of flow conversion systems. The engine allows for the imitation of variable flow rates. The VECTOR was developed by the alliance partner
Fraunhofer IFF Magdeburg and is operated by the company SIBAU Genthin GmbH & Co. KG.

Figure 5 – Vector [5] und Prototype 1 on VECTOR

The first prototype was mounted under the VECTOR. Flow sensors were installed in front of and behind the rotor. Furthermore, an underwater camera was placed at the turbine entrance. This should document the movement of the flow. The VECTOR was then used to run tests at a specified speed. The rotor speed was specified and increased in each case in 10 percentage steps. The electricity generated and consumed by the generator was measured and it was possible by means of a conversion factor to directly draw conclusions about the immediate force of the generator and thus finally also about the power generated. Figure 6 shows the power coefficient cp over the speed coefficient λ for the prototype 1.

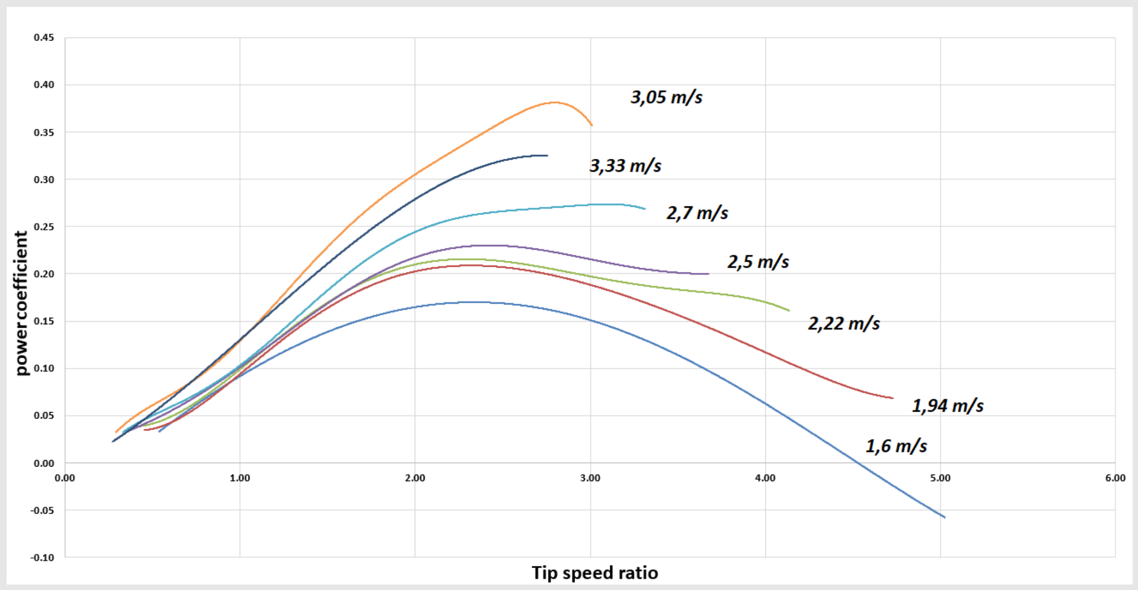

Figure 6 - Cp-Value Turbine 1

The desired cp value for the prototype 1 is cp = 0.43. In the area of the design speed coefficient $\lambda_A = 3.3$, the system has a real power coefficient of 0.32. The grate, which is not taken into account in the design, and the placement of lamps, camera and flow probes in the inflow area contribute to a reduction of the power coefficient. Furthermore, strong turbulences were observed in front of and beside the turbine, especially at higher speeds. Figure 7 shows the performance of the first prototype versus speed at a fixed flow rate. At the design speed of 120 rpm, achievable power levels of 250 - 1000 watts are realistic. Higher flow velocities are usually not achieved, and thus achievements above 1250 watts can be excluded.

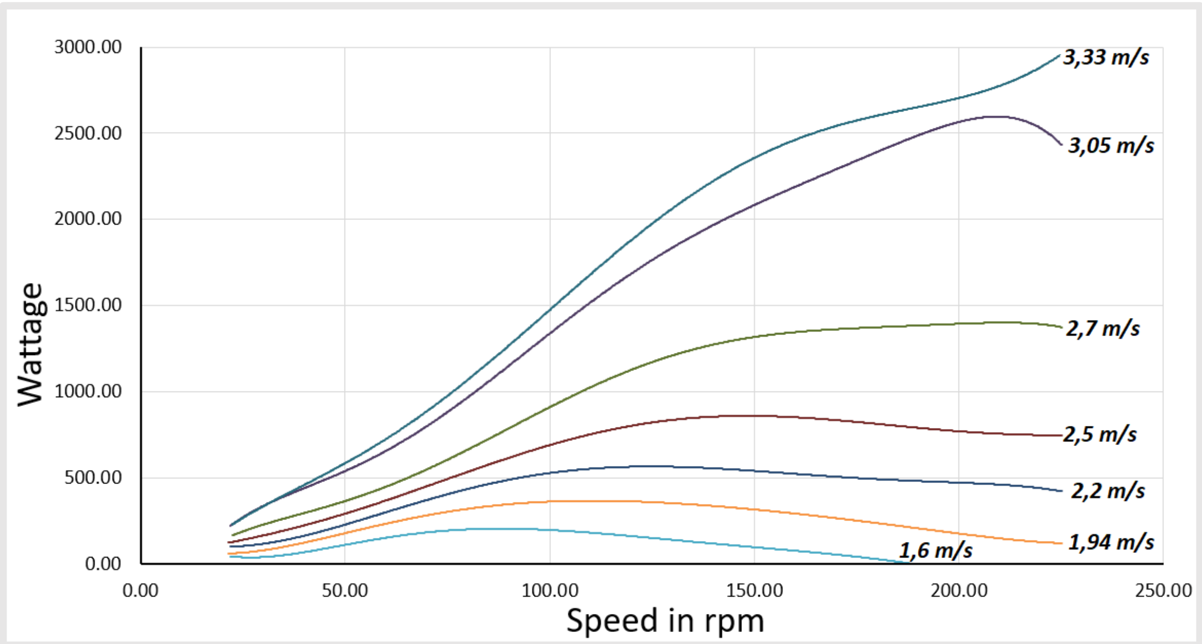

Figure 7 - Power Turbine 1

The hydrokinetic turbine, especially the second prototype, was designed for self-sufficient energy supply in developing regions. Due to this, the costs for design and production of an individual system were reduced. To increase the mobility, the overall construction was made as compact and weight-reduced as possible. It should be possible to transport the construction,

Figure 8 - Turbine 2 in River Bode

especially in hard to reach areas, by pick-ups or smaller trucks. In order to be able to test the prototype 2 extensively, an endurance test under real conditions in a river section in the river Bode in the region Neugattersleben near Magdeburg was deemed necessary (Fig. 8).

For this purpose, the turbine was lifted by crane into the river and fixed in the middle with ropes. The two-month test procedure provided information about the flow behavior in flowing water, especially the orientation of the turbine at different flow velocities, and the influence of accumulated flotsam of any kind. With a few minor improvements, the system could be positioned in perfect balance in the river, regardless of the flow rate. The problem of the flotsam has not yet been completely clarified. In particular, smaller trapped aquatic plants can adversely affect the machine, since they accumulate at the grate that is intended for protection and fish.

4. Conclusion

When working on the project, two prototypes of the hydrokinetic turbines were developed and manufactured with the help of cooperation partners from the relevant industry, and tested both in a channel under given conditions and in the extended test in the river. This laid the foundation for the development of a hydrokinetic turbine ready for serial production. The development of the hydrokinetic turbines was done with both a coated impeller and a free-running rotor unit. The coating should thereby both increase performance and generate buoyancy. Until now, the gradient heights below that of the Kaplan turbines was an unexplored field of application. This should be harnessed by the development of hydrokinetic turbines. In order to determine a broad scope of performance, the mapping of the first prototype was carried out under controlled conditions on the research test carrier VECTOR for different flow velocities. The system generated a power up to 1000 watts at realistic flow speeds. The second prototype was subjected to an extended test at the test site Neugattersleben near Magdeburg. It showed problems with a horizontal alignment of the entire turbine to the surface of the water, which could be remedied by adjusting the trim device. Furthermore, there are various findings on the influence of the closely-meshed fish grate on the performance of the turbine, as well as the influence of accumulated floating debris in the river. Therefore the choice of location should be made taking both of these aspects into account. Due to the rotation of the impeller and the associated secondary flows, an ecological upgrading of the river section on which the extended tests were carried out was able to be achieved.

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