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Open channel velocity field investigation for hydrokinetic power generation

Alexander Stanilov, *Iskra* Simova, *Rositsa* Velichkova*, *Elitsa* Gieva, and *Rangel* Sharkov

Technical University of Sofia, 1000 Sofia, Bulgaria

Abstract. The paper presents an experimental study of a velocity field in an open channel. The study of water flow in an open channel is complicated due to the influence of various factors and different variables. Some of the variables affecting the flow parameters include the height of the water column, the width of the channel, the length of the channel, the slope of the channel, and the conditions of the channel bed. The investigated open channel is used for experimental research of kinetic turbines, and the flow speed in the channel is in the range of 0.1-0.3 m/s. The low velocity values in the channel are driven by the operation of the kinetic water turbines in real-world conditions. When describing the test channel, the influence of several boundary conditions has been taken into account, such as protrusions between the measurement sections, the water level, and disturbing effects. Results for the velocity fields determined in five sections of the test open channel are given. A turbine and an electromagnetic probe were used for the experiments. A comparison between the results obtained with the two measuring instruments under the same flow conditions in the test channel is made. The results for the velocity variation in the test sections for the maximum velocity in the channel are presented. At this maximum water velocity, the test channel maintains a water level of approximately 150 mm. The experimental data is also illustrated graphically, along with the velocity fluctuations along the channel centreline. The results obtained provide an idea of the expected velocity fields in the measurement open channel and the relative magnitude of the fluctuations in the different measurement sections.

1 Introduction

The study of the flow in open channels, particularly the measurement of the velocity field, is of crucial importance for understanding and optimizing the operation of hydrokinetic turbines. Hydrokinetic turbines harness the kinetic energy of flowing water. These turbines are particularly suitable for applications involving the utilization of energy from rivers, as well as tidal energy [1].

There are several factors related to the open channels flows investigation that contribute to the efficiency and performance of hydrokinetic turbines:

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* Corresponding author: rvelichkova@tu-sofia.bg

Flow velocity: The velocity of water in the open channel directly influences the amount of energy that can be extracted from it. Higher flow velocities lead to greater kinetic energy that can be utilized for electricity generation. Studying the flow helps to determine the type of kinetic turbine suitable for given conditions (flow velocity and depth) [2].

Flow depth: The depth of the water flow in the open channel affects the operation of kinetic turbines by directly determining the active (working) area of the turbines.

Channel geometry: The open channel shape and size play an important role in determining the flow distribution and water velocity. Optimizing the channel geometry can help improve the efficiency of the kinetic hydro turbine by providing a uniform and predictable flow of water to the turbine.

Turbulence: Open channel flows are often turbulent, which can affect the operation of kinetic hydro turbines. Turbulent flow can lead to energy losses due to viscous forces and the formation of vortices. Studying the flow helps understand the level of turbulence and develop strategies to minimize the negative impacts on turbine performance [3, 4].

Velocity variability: The flow velocity in open channels often varies around a mean value. Determining the variability can provide insights into its impact on the operation of the hydrokinetic turbine, including fluctuations in the turbine rotation frequency.

In summary, studying flow in open channels is essential for understanding and optimizing the operation of hydrokinetic turbines. By examining factors such as flow velocity, depth, channel geometry, turbulence, and flow variability.

The aim of this paper is to study experimentally the velocity field in an open channel designed for testing hydrokinetic turbines, with the maximum water velocity ranging from 0.1 to 0.3 m/s.

2 Measurement of velocity in open channels

The study of water flow in an open channel can be more challenging due to the influence of various factors and variables [5]. Some of the variables affecting the flow parameters include, for example, the water column height, channel width, channel length, channel slope, and bottom channel conditions [6]. These variables interact in complex ways, making it difficult to isolate and understand their individual effects. Boundary conditions in the open channel also influence the dynamics of velocity. One of the boundary conditions is the shape and roughness of the channel walls, which can vary in terms of their shape, material, and roughness. All these parameters directly affect the velocity measurements in open channels [7, 8]. Outside laboratory conditions, environmental factors also has to be encountered. Environmental factors such as wind, precipitation, and temperature changes can also affect the flow of water in an open channel. These factors can be challenging to measure and account for, further complicating the studies.

The velocity profiles depend on the channel shape, the depth of the flow, and the velocity of the flow. Free surface waves are usually present, and unlike in closed pipes where the highest velocity occurs near the center of the pipe, in open channels, it occurs at 5 to 25% of the depth below the surface.

All the mentioned factors influence the measurements regarding the determination of the velocity field in an open channel.

The methods for measuring velocity at a specific point in an open channel typically involve the use of classical Pitot tubes working on the principle of pressure difference, turbine velocity probes, and electromagnetic heated probes. For low-velocity flows, the use of Pitot tube velocity meters operating on pressure difference is limited by the fact that the dynamic pressure component has a low value, leading to greater measurement error or the need for a device to measure very low pressures to minimize measurement error.

3 Open channel parameters

The open channel is designed and manufactured for testing micro kinetic water turbines with a working wheel diameter of up to 100mm [9]. The channel is shown in Fig.1. The outlet section of the channel has a triangular shape, aiming to achieve the desired maximum velocity for the operation of the kinetic turbine in the central section of the channel. The channel consists of two sections (test sections), each with a length of 1500mm. In the first test section, a transparent screen is installed to observe the flow. The screen is mounted so as not to form any indentations or protrusions on the inner side of the channel. Water enters both test sections, with the first passing through a diffuser.

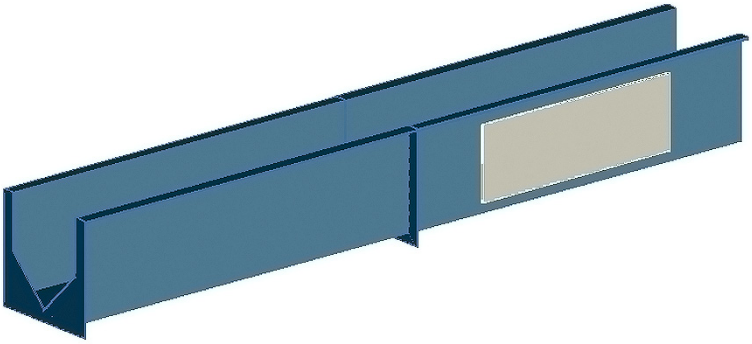

Fig.1. Open channel measurement sections.

Before starting the measurements, an analysis of the factors affecting the uniformity of the flow was conducted. The channel has a constant rectangular cross-section, and control measurements of the geometric shape were made at three sections for each of the sections. The channel is set at a minimal inclination angle of 50 degrees. The channel itself can adjust its inclination using braces mounted on it. A layer of anti-corrosion coating has been applied to the entire channel, ensuring uniformity of roughness to a certain extent. The only non-uniformity occurs at the junction of the two test sections to each other. The depth of the flow is measured after removing the velocity measuring device to avoid influencing the measurement.

4 Experimental study of the velocity field

Figure 2 shows the test rig used for determining the velocity field. It consists of the following components: main reservoir - 1, pump - 2, shut-off and control fittings - 3, 4, straightening grids - 5, stone grid - 6, level measurement lines - 7, observation hatch - 8, test sections - 9 and 11, and conveying element - 12. The following technical devices for velocity measurement are also included in the rig: electromagnetic submersible probe type ABB Aqua Probe and turbine velocity probe flowatch flowmeter - 10.

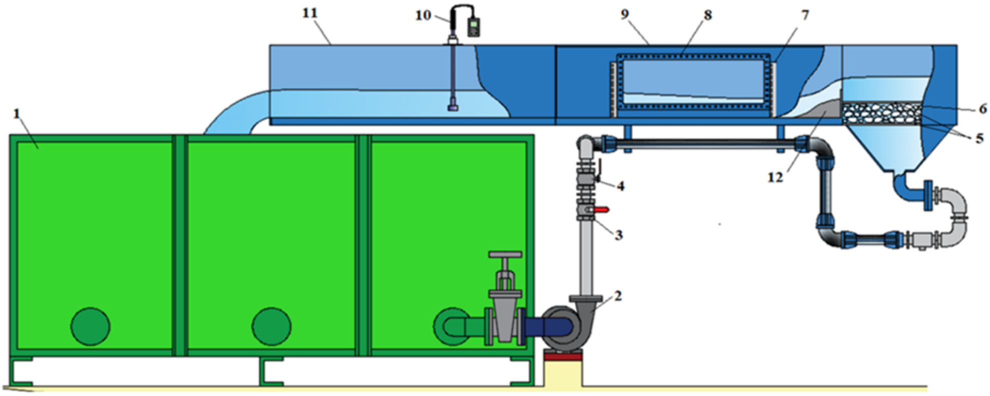

Fig. 2. Open channel velocity field measurements test rig.

The procedure for studying the velocity field is as follows: The pump unit 2 is started, and valves 3 and 4 are sequentially opened. Initially, valve 4 is opened to 100% to set the maximum speed mode. The other modes are set by gradually closing valve 4 while monitoring the water level in the test sections. Water enters the test sections sequentially, passing through the straightening grids 5 and the stone grid 6. The use of stones enclosed between the two straightening grids is intended to reduce water pressure, thus approximating the flow in an open channel. Before entering measurement sections 9 and 11, the water passes through the diffuser 12. With this setup, the turbine velocity probe is placed, and velocities are measured at the points indicated in Figure 3.

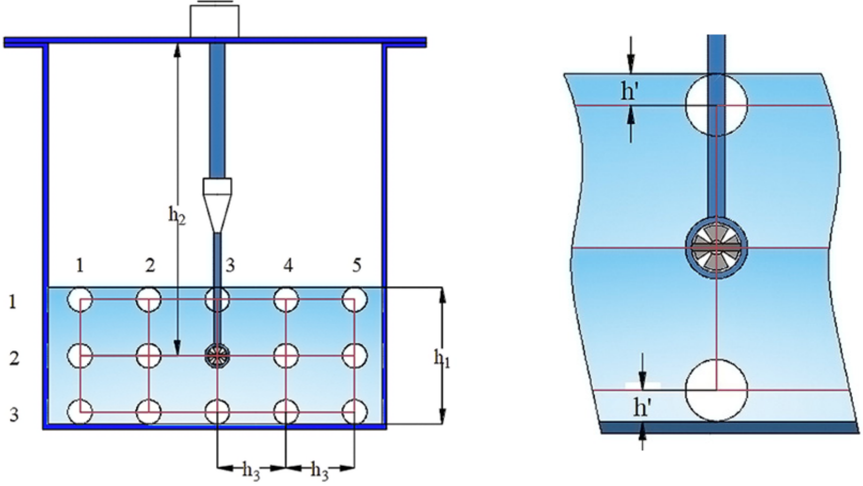

Fig. 3. Turbine velocity meter measurement points.

For a given operating mode and a specific flow depth h_1, the position for placing the velocity probe is determined. The probe is positioned to measure velocities in three longitudinal and five transverse sections. The vertical positioning is controlled by setting the height h_2, representing the vertical position for each measurement point. Horizontal distances are set by moving the probe along the plane placed on the test sections, with holes made on it for positioning the holding device, where the axes of the holes correspond to the distance h_3. The error in positioning the velocity probe in both directions is within ±1mm.

After completing the measurements, the electromagnetic submersible probe is placed, and the measurements are repeated, but only for the average velocity field shown in Figure 4 (measurement sections 1-5).

The measurement is conducted under the same conditions but only for a single average cross-section. The measurements are carried out for a single section due to the minimum distance from the sensors to the free surface (h_{min}). An electromagnetic probe is used because of its ability to continuously record values at 15-second intervals. This way, we determine the velocity fluctuations for each cross-section.

The selected measurement points for the velocity field are aligned with the position where the kinetic turbine is installed in a given cross-section.

The cross-sections where velocity field measurements are taken are indicated in Figure 4.

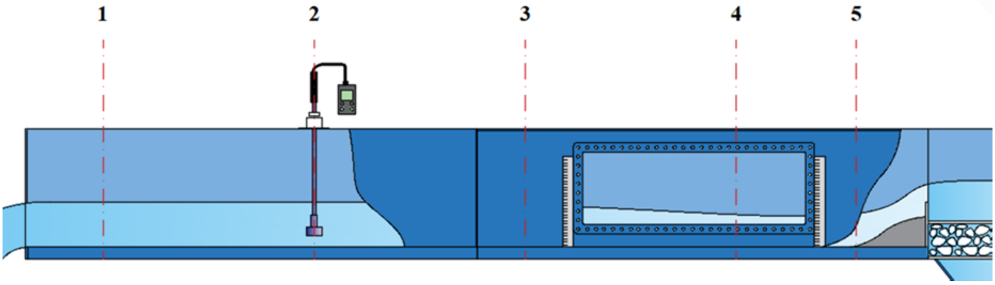

Fig. 4. Measurement sections 1-5.

5 Results and discussion

Two experiments are conducted to form the velocity field in the research channel. The first one is performed using the turbine velocity probe according to the methodology shown in Figure 3, and the obtained results are presented in Table 1. The graphical representation of the data is shown in Figures 5, 6, and 7.

Table 1. Velocity field measured data.

\	Level	Velocity in measuring points, m/s				
		1	2	3	4	5
1		h_1=150mm				
	Level 1	0.250	0.264	0.306	0.278	0.250
	Level 2	0.194	0.222	0.264	0.222	0.222
	Level 3	0.153	0.167	0.194	0.167	0.167
2		h_1=150mm				
	Level 1	0.306	0.306	0.333	0.278	0.194
	Level 2	0.222	0.278	0.278	0.222	0.167
	Level 3	0.194	0.194	0.194	0.167	0.139
3		h_1=135mm				
	Level 1	0.333	0.333	0.306	0.222	0.194
	Level 2	0.278	0.250	0.222	0.194	0.167
	Level 3	0.278	0.222	0.222	0.194	0.083

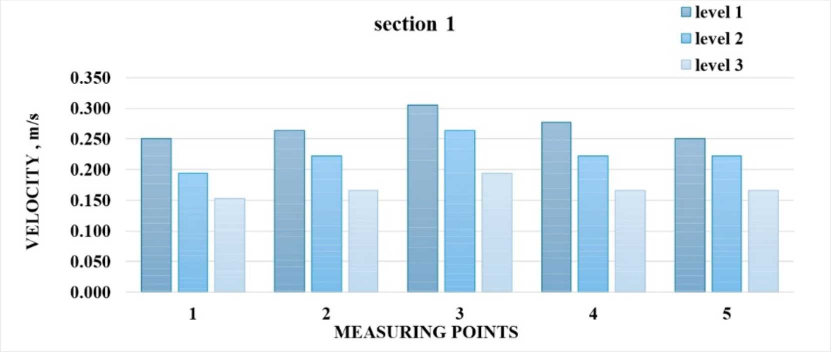

Fig. 5. Velocity field at section 1.

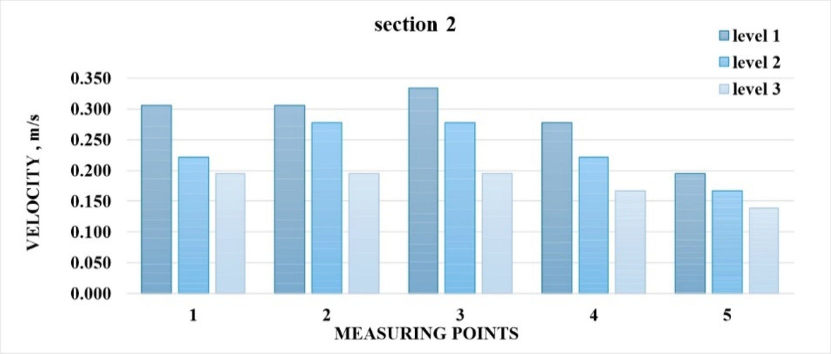

Fig. 6. Velocity field at section 2.

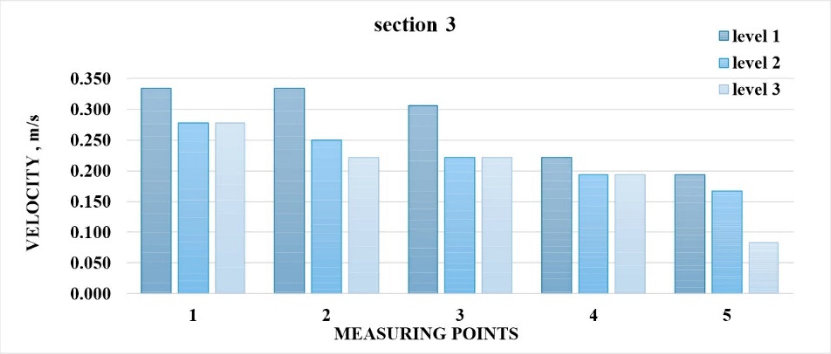

Fig. 7. Velocity field at section 3.

The obtained data for the measured velocity field, presented in tabular and graphical form, show that the flow rate non-uniformity decreases as the measurement section 1 is approached. This indicates that for the respective maximum velocity of 0.3 m/s, the investigated open channel has insufficient length. In order to reduce velocity fluctuations, it is necessary to extend the investigated channel with at least one more section for this velocity field.

From Figures 6 and 7, a delay in velocity at point 5 and asymmetry in the velocity field, influenced by the connection of the measurement sections, can be observed. A completely asymmetric velocity field for section 3 clearly indicates once again the insufficient length of the channel for the maximum test velocity. In sections 4 and 5, unsteady flow with large velocity fluctuations is observed.

Sections 4 and 5 are close to the entrance of the measuring sections, where the flow has stabilized. The data from the measurements are purely illustrative and cannot be considered reliable due to large fluctuations and measured values. The obtained results are presented in Table 2.

Table 2. Velocity field data for sections 4 and 5.

Section	**Level**	**Velocity in measuring points, m/s**				
		1	2	3	4	5
4		h_1=125 mm				
	Level 3	0.278-0.444	0.306-0.472	0.278-0.361	0.222-0.444	0.250-0.361
5		h_1=120 mm				
	Level 3	0.611-0.667	0.639-0.667	0.639-0.941	0.639-0.667	0.583-0.611

From Table 2, it can be seen that velocity field values were measured only for level 3 (the level near the bottom of the tank), and while for section 4 the velocity fluctuates by up to two times above the minimum, in section 5 these pulsations are within 10%, mainly due to the operation of the flow stabilizer.

The second test is conducted using the electromagnetic submerged probe following the methodology outlined in Figure 3 to determine the variation of velocity at a given point over time. Figure 8 shows the graph for the central points of the three measuring sections.

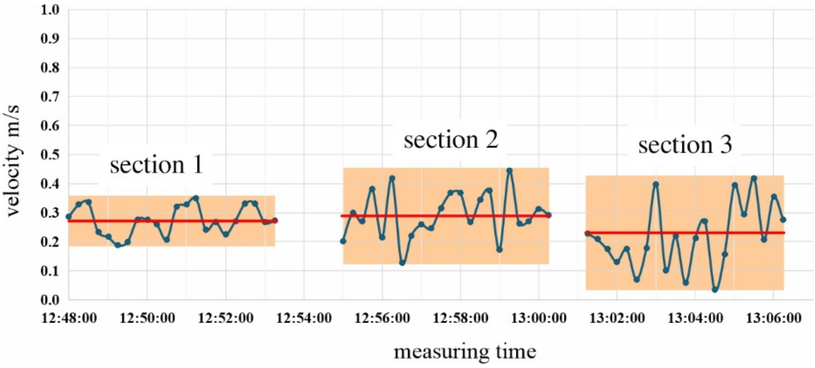

Fig. 8. Variation of velocities measured with the electromagnetic probe

Using two different measuring instruments leads to measurement discrepancies. Therefore, Table 3 and Figure 9 provide a comparison between the average velocity values at the same points determined by the two measuring instruments.

Table 3. Measuring instruments comparison.

Average velocity, m/s	
flowatch	Aqua Probe
0.264	0.273
0.278	0.292
0.222	0.217

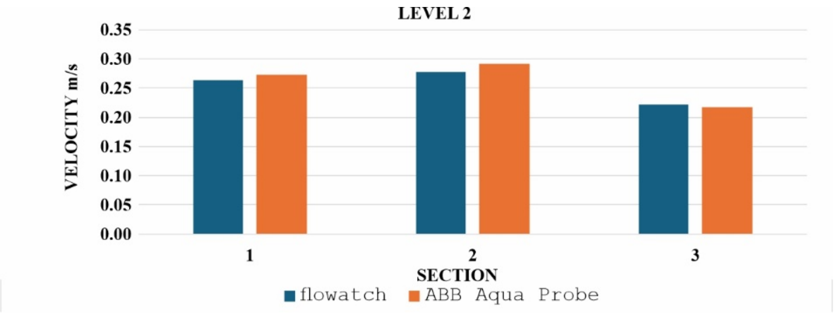

Fig. 9. Measuring instruments readings comparison.

6 Conclusion

The paper presents a detailed investigation into the factors affecting velocity in open channels for optimizing the design and efficiency of hydrokinetic turbines.

The conducted test measurements in the studied open channel were carried out in three directions as follows:

• A study was conducted to determine the velocity fields in measurement sections 1 to 3, with the results provided in Table 1 and Figures 5 to 7. Additionally, an investigation of the unsteady flow in sections 4 and 5 was conducted, with the results provided in Table 2.

• Studies have been conducted to determine the velocity non-uniformity along the centerline of the channel, with the results shown in Figure 8.

• A comparison of the two velocity measuring instruments was made, with the results graphically presented in Table 3 and Figure 9.

For the given channel, it would be most appropriate to conduct research on kinetic turbines in the area between sections 1 and 2. Despite the conducted laboratory studies, it is advisable to anticipate and measure the velocity field in real-world conditions as well.

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