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An experimental facility for the development of a gravitational water vortex turbine

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Research problem

Gravitational water vortex turbine (GVT) is a run-of-the-river hydroelectric system used for generating electricity in the absence of a large dam and a reservoir; i.e., GVT generates power using the water natural flow rate. Recently, the development of GVT is gaining a growing interest within the scientific community concerning the advantages associated with the technology in the process of electric power production. This work describes the design of an experimental facility for the characterization of a GVT in order to understand in a detailed way the effect of the variation of hydrodynamic and geometric parameters on the performance curve of the turbine.

Keywords: Gravitational water vortex hydraulic turbine, runner, efficiency, hydropower

Material and methods

Objetive

The aim of this work is to present the development of an experimental facility that has been specifically designed for the purpose of studying GVT. The facility allows for the testing of several geometric configurations and design parameters, which are essential for optimizing the performance of these turbines. The installation is designed to create a controlled environment in which the behaviour of the turbine can be observed and manipulated under different operating conditions.

The experimental setup conducted consists of a reservoir with a capacity of 2 m^3, a centrifugal pump, an input tank with a capacity of 0.18 m^3, which can be coupled with the GVT, consisting of an inlet channel that is flanged to the input tank, a discharge chamber, and a runner. The reservoir was made of fiberglass reinforced with an outer steel structure and input tank was made of 14-gauge steel sheets. The shaft of the turbine is supported on a structure located at the top of the discharge chamber. At the end of the turbine shaft, a torque sensor is coupled, and a motor is connected to the output of the torque sensor, which is used to apply load on the turbine and depict the efficiency curve of the GVT. Fig 1 shows the experimental facility.

The operation of the experimental bench can be described as follows: 1) the IHM 30A-15W-IE2 pump facilitated the transfer of water from the reservoir tank to the inlet tank of the GVT system., 2) a SITRANS F M MAG 5100 W flow sensor from Siemens was connected to the PLC, which enabled the system to measure the mass flow of water circulating through the GVT system, 3) the inlet tank was filled with water from the bottom, causing the level to rise until it spills over into the inlet channel and then into the discharge chamber, forming a vortex that emptied into the reservoir tank. Finally, 4) the turbine was situated where the vortex made contact, and it was linked to the measurement and control system via a vertical axis.

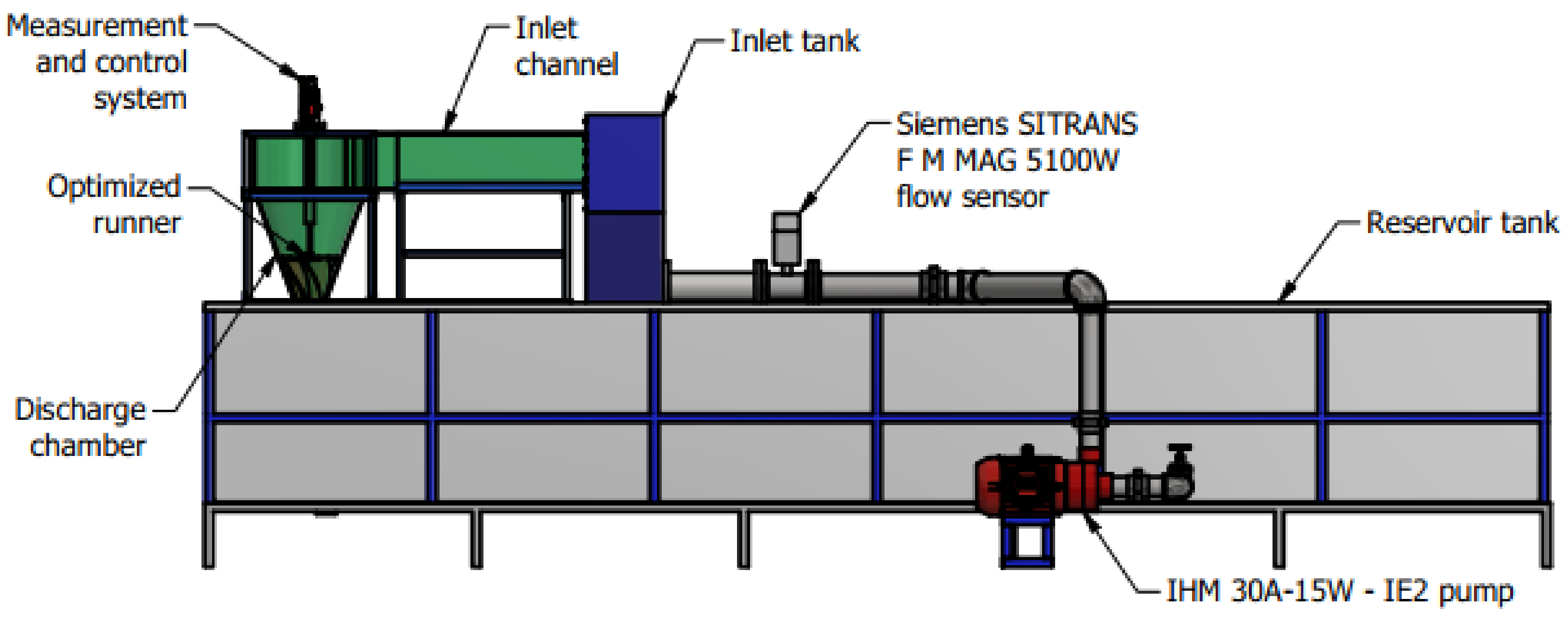

Fig. 1. Experimental facility for the development of the GVT

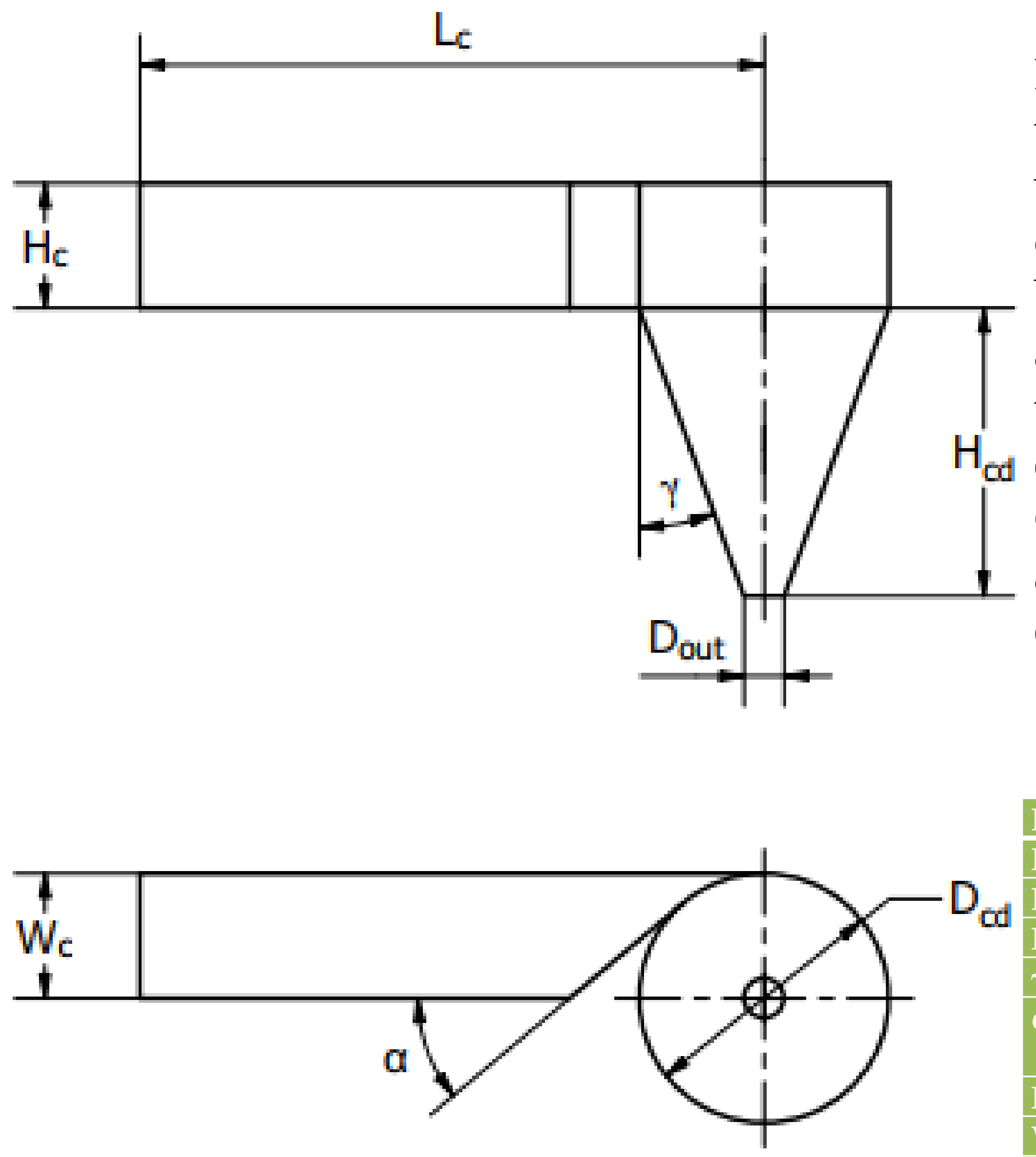

Fig 2. The main factors that define the geometry of the chosen system discharge channel and chamber.

Fig 2. illustrates the parameters used to define the system geometry and provides specific values for the factors that define the geometries of the inlet channel and the discharge chamber, based on the chosen design. A 5 mm thick acrylic sheet, transparent in nature, was used in the construction of both the inlet channel and the discharge chamber. The entrance channel of the GVT features a rectangular cross-sectional area and a conical discharge chamber, which is designed to be adapted to the runner geometry.

Factor	Description	Value
D_{cd}	Upper chamber diameter	500 mm
D_{out}	Outlet diameter	80 mm
H_{cd}	Height of the discharge chamber	577 mm
γ	Cone angle	20°
α	Angle between the inlet channel and the discharge chamber	40°
Hc	Height of the inlet channel	250 mm
W_c	Width of the inlet channel	250 mm
L_c	Length of the inlet channel	1250 mm
$D_{out/}D_{cd}$	Diameter ratio	0.16

The main components used to gauge and regulate the turbine performance are illustrated in Fig. 3. The Pololu 4741 motor was utilized to oppose the runner rotation, acting like a brake or electric generator by energizing itself in the opposite direction of the free surface vortex. An Arduino Nano board controlled this motor via an H-bridge, enabling the power delivered from a DC source to the motor to be adjusted using Pulse Width Modulation (PWM). The Arduino was programmed to increase the pulse width percentage at 12-second intervals, resulting in a corresponding increase in braking power.

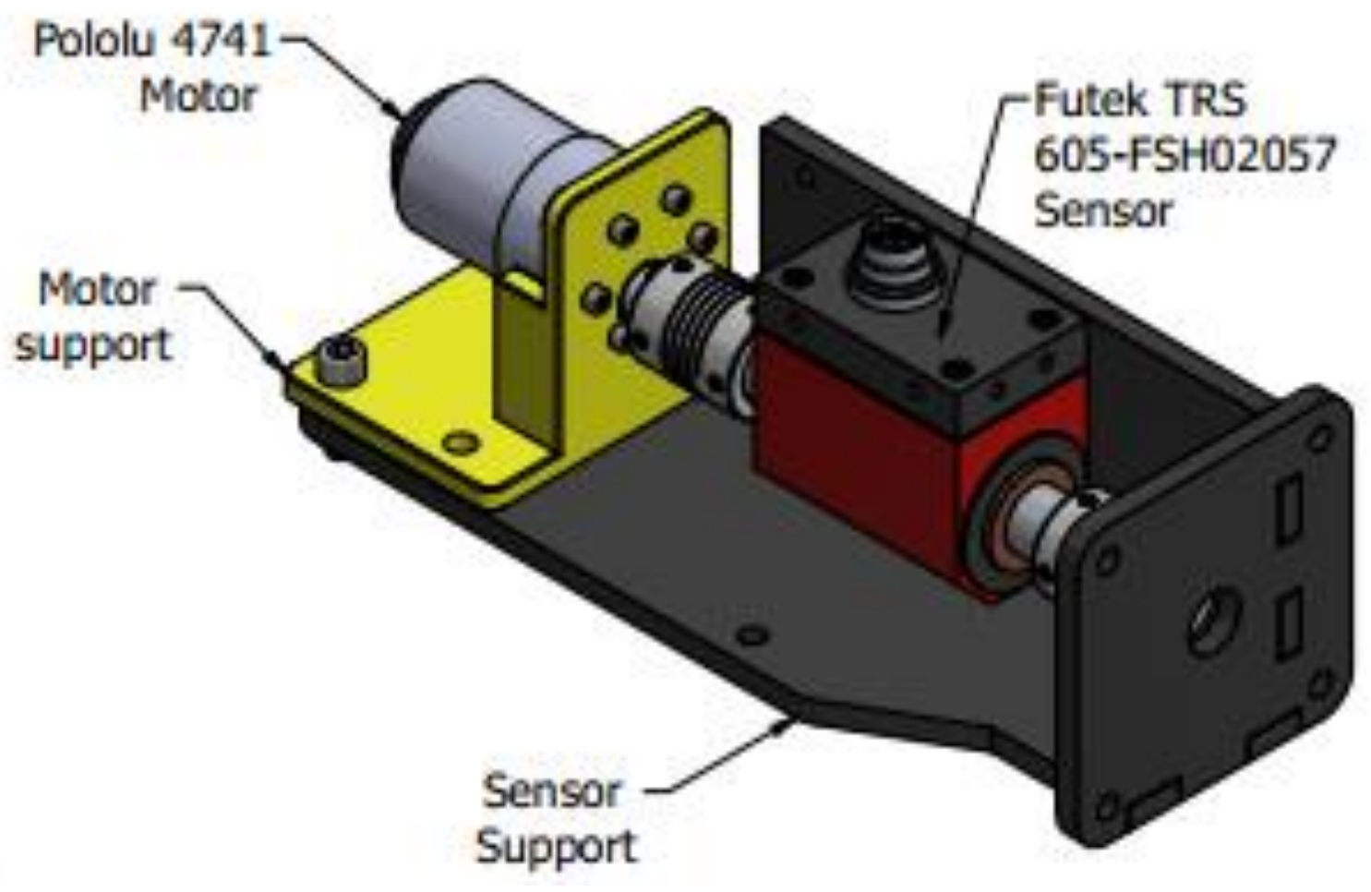

Fig 3. Assemble of measurement and control system

In Fig. 4, the runner geometry can be observed, which is characterized by six blades, a twist angle of 55, an upper runner diameter to upper chamber diameter ratio of 0.5, and a bottom runner diameter to upper chamber diameter ratio of 0.23.

Fig 4. The designed GVT runner

Results and discussion

Understanding the impact of circulation on the formation of the vortex is crucial for optimizing the GVT design and improving its overall efficiency. Using the experimental facility development in this work was studied, the behaviour of the vortex for four different flow velocities (0.04, 0.05, 0.06 and 0.07 m/s) in the inlet channel is shown in Fig. 5. In the figure, the formation of the vortex can be observed. This figure provides visual evidence of how the vortex varies as the flow velocity changes, highlighting the importance of the flow rate in the vortex formation and strength.

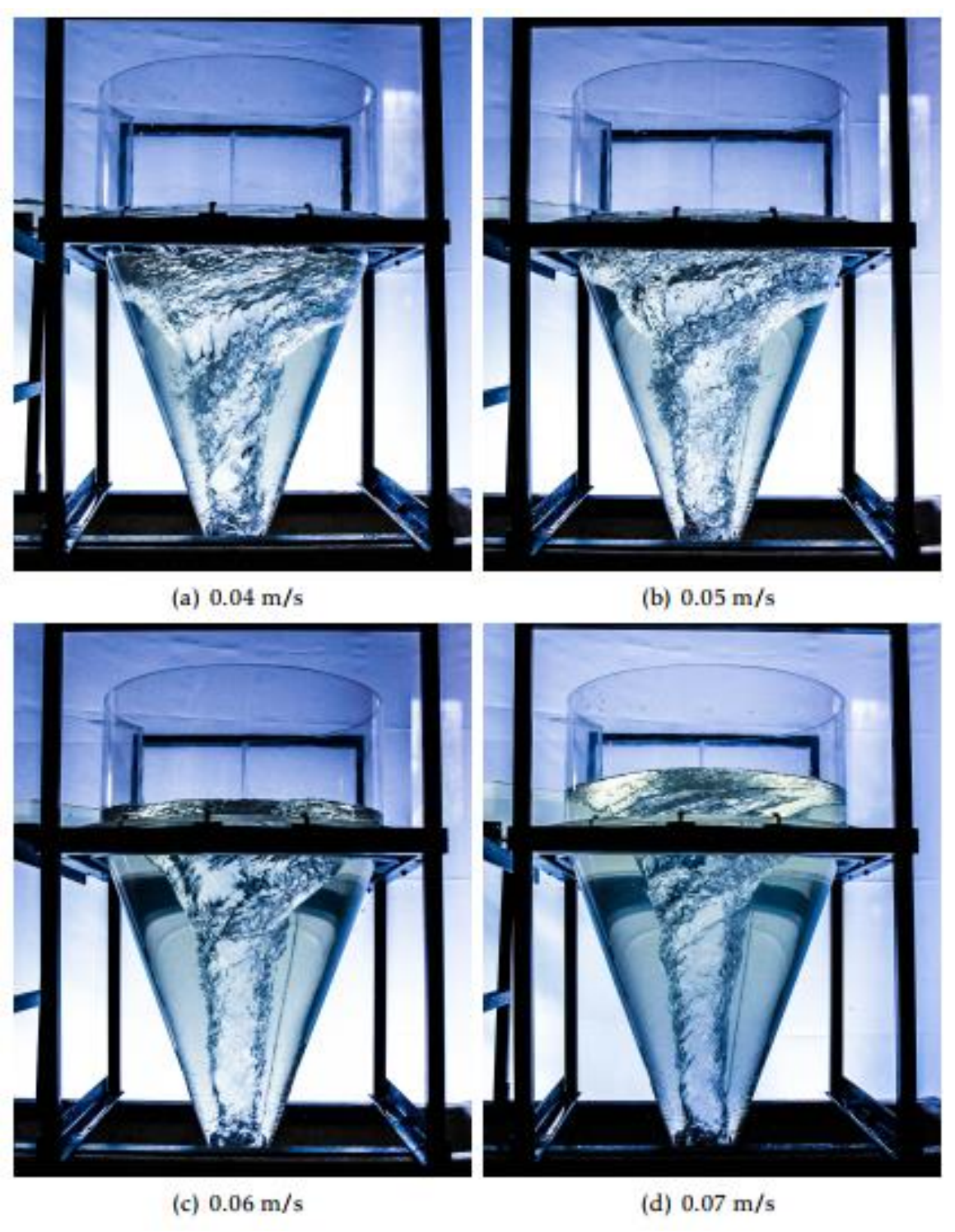
(a) 0.04 m/s (b) 0.05 m/s
(c) 0.06 m/s (d) 0.07 m/s

Fig. 5. Efficiency vs. angular velocity.

When the inlet velocity was high, a narrower vortex was generated because the fluid flow had less time to be expanded in the discharge chamber. On the other hand, when the inlet velocity was low, a wider vortex was generated because the fluid flow had more time to be expanded in the discharge chamber. It is important to note that, in addition to the inlet velocity, other factors can also influence the width of the vortex in a GVT, such as the geometry of the discharge chamber, the shape of the runner, and the viscosity of the fluid.

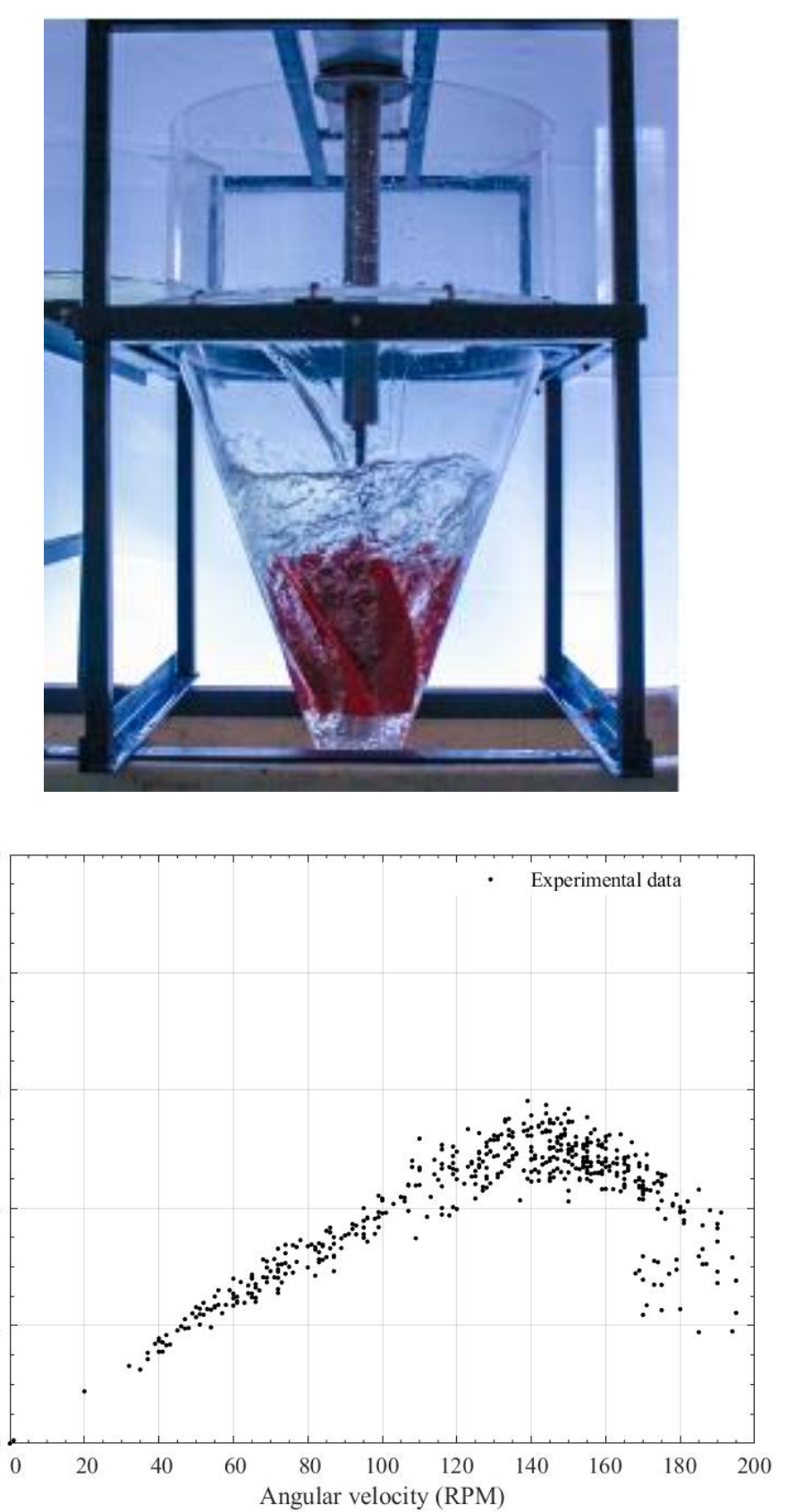

Fig 6. Interaction of the vortex with the runner

Fig. 6 also shows the GVT efficiency curve. This efficiency can be defined as the ratio of the energy output to the energy input. In the current study, it was determined experimentally by measuring the power output and the flow rate of the fluid. By varying the angular velocity of the turbine and measuring the corresponding power output and flow rate, the efficiency curve can be generated. Typically, the GVT efficiency is highest at a specific angular velocity, known as the optimum point. Beyond this point, the turbine efficiency decreases due to increased friction and energy losses. By analysing the efficiency curve of the target GVT, the optimum point allowing an efficiency of 0.495 was identified at 140.25 rpm.

Conclusion

The development of experimental facilities is crucial for advancing in the field of GVT. Modular GVT with interchangeable parts can greatly facilitate the testing and development process. A strong vortex in the discharge chamber of a gravitational vortex turbine is crucial for achieving optimal performance. The vortex helps to create a low-pressure zone at the center of the turbine, which results in increased rotational speed and higher energy conversion efficiency. The wider vortex generated at low inlet velocities presents an opportunity for maximizing the energy output of the turbine. During experimental tests on the designed bench, it was observed that a narrower vortex was generated when the inlet velocity was high, as the fluid flow had less time to expand in the discharge chamber. Conversely, a wider vortex was generated when the inlet velocity was low, as the fluid flow had more time to expand in the discharge chamber. It should be noted that factors such as the geometry of the discharge chamber, the shape of the runner, and the viscosity of the fluid, in addition to the inlet velocity, can also influence the width of the vortex in a GVT.

By analysing the efficiency curve of the turbine, the optimal operating point can be identified so that the maximum efficiency is achieved. In the GVT experimental testing, an efficiency of 0.495 was achieved at 140.25 rpm. In this regard, the continued research and development of these turbines have the potential to contribute to the production of clean and sustainable energy.

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