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CFD Simulation of Five Blades Archimedes Screw Turbine as Alternative Power Plant for Traditional Fishing Boat

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Abstract

The need for electrical energy for traditional fishermen has greatly increased, considering that almost all equipment is now powered by electricity. Archimedes screw turbines, which are generally used as micro hydro power plants, especially in rivers or dams that incline, can be used as an alternative power generator for traditional fishing boats. This research aims to determine the performance of a five-blade Archimedes screw turbine using Ansys CFX software. The simulation was carried out with a flow velocity at the inlet boundary of 2.5 m/s using the transient simulation method, in order to obtain information about the flow characteristics around the turbine as the turbine rotates. So that the turbine can rotate during the simulation, the turbine domain is set using a Rigid Body Solution, so that its rotation will be influenced by the flow rate entering the turbine as is done in the laboratory. The results of this research will be used to optimize the performance of the turbine so that it can produce maximum power. From the simulation and analysis carried out, it was obtained that the mechanical power was 0.08 Watts and the hydraulic power was 0.49 Watts with a turbine efficiency of 17.28%. Apart from that, the increase in rotation produced by the turbine due to the hydraulic power of the water is directly proportional to the increase in mechanical power and torque in the turbine. The low value of mechanical power and efficiency obtained in this research is caused by the absence of an inclination angle between the inlet and outlet parts of the turbine.

Keywords: *Archimedes screw turbine; transient simulation; rigid body solution*

1. Introduction

The use of Archimedes screw turbines in micro-hydro power plants is one of the current options [1]. This is because this type of turbine has advantages not only economically but also environmentally [2]. One of the advantages of this turbine is ease of installation, durability and the ability to operate in unclean water conditions [3].

In the maritime world, especially on traditional fishing boats, the use of turbines can be used as an alternative power generator by modifying the outrigger shape [4]. In designing a turbine that will be implemented on an outrigger, several components must be considered, such as the diameter ratio, pitch ratio and length of the turbine. This component influences the electrical energy that can be generated by the turbine [1], [5].

Selecting the right dimensions can produce optimal turbine rotation [5], [6]. Apart from that, one factor that must be considered is the selection of the number of blades [7], considering that the increase in flow rate, turbine rotation, torque and power produced is not directly proportional to the increase in efficiency of the turbine itself [8], [9].

In general, the use of Archimedes screw turbines as micro-hydro power plants are installed at a certain tilt angle [1]–[3], [7], [8], this is certainly difficult to apply to ship outriggers. To overcome this, a turbine with a larger number of blades was chosen [4], [10]. Increasing the number of blades provides increased turbine performance, especially when operating at low speeds and small water volumes [10], [11].

This research aims to analyze the performance of a five blades Archimedes screw turbine used as an alternative power generator on traditional fishing boats in the South Sulawesi region, Indonesia.

2. Methods

The planning of the Archimedes screw turbine in this study is limited by the dimensions of the outrigger, both diameter and length, to maintain the initial function of the outrigger as a stabilizer. From previous research [4], the optimal turbine dimensions applied to the outriggers were obtained as presented in Table 1.

In Fig. 1, a two-dimensional view of the turbine profile is presented which can be used to calculate the optimal diameter and pitch ratio with the help of nondimensional parameters [12], such as

$$Radius\ Ratio = \frac{Ri}{Ro} \quad (1)$$

$$Pitch\ Ratio = \frac{P}{2\pi Ro} \quad (2)$$

Table 1. Turbine dimension [4]

Symbol	Name	Value
Di	Thread inside diameter	0.03 m
Do	Thread outside diameter	0.096 m
L	Turbine length	0.12 m
β	Thread angle at Di position	34º
α	Thread angle at Do position	65º
n	Number of blades	5
P	Pitch	0.140 m

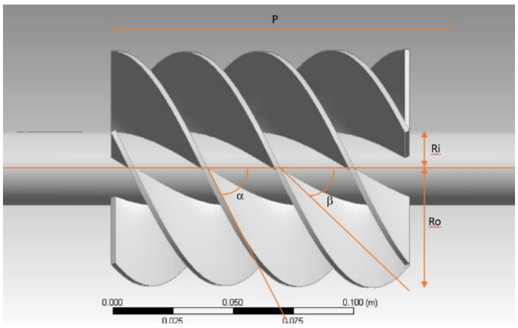


Figure 1. Two-dimensional view of five blades turbine

The installation of the turbine on the outrigger is shown in Fig. 2. The clearance between the turbine and the outrigger is 0.028 m, with a radius ratio of 0.3125 and a pitch ratio of 0.2322. Clearance is kept as small as possible to avoid reducing turbine efficiency due to large amounts of flow not hitting the blades.

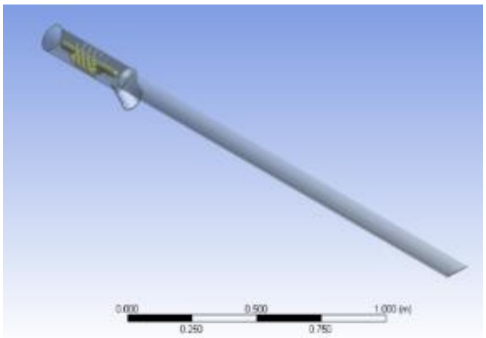


Figure 2. Outrigger and turbine model on Ansys

Turbine operational conditions depend on the flow rate (Q) in m^3/s, angular velocity (ω) in m/s and the height difference between the inlet and outlet (H) in m [5]. In this research, the H value is obtained from the difference between the radius of the turbine and the height of the immersed part of the turbine. The hydraulic power (Ph) supplied by water to the turbine is calculated using the formula [5], [7].

$$P_h = \rho g Q H \text{ (Watt)} \quad (3)$$

Where ρ is the density of water (kg/m^3) and g is the acceleration due to gravity (m/s^2).

The mechanical power (Pm) produced by the turbine due to the push from the water can be calculated as seen in equation 4 [5], [7].

$$P_m = T\ \omega \text{ (Watt)} \quad (4)$$

$$\omega = 2\pi n \quad (5)$$

Where T is the torque of the turbine (Nm) and n is the turbine rotation in rps.

By comparing the supply power (Ph) with the generated power (Pm), the efficiency of the Archimedes screw turbine can be obtained as follows [5], [7].

$$\eta = \frac{P_m}{P_h} x100\% \quad (6)$$

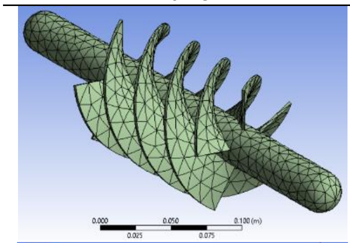
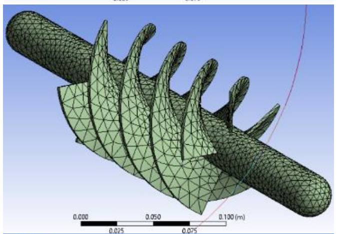
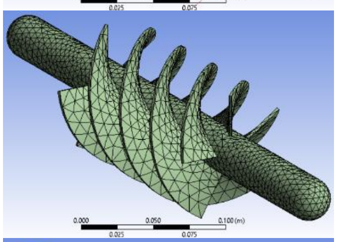
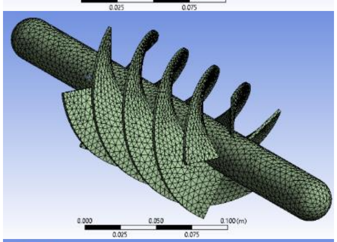
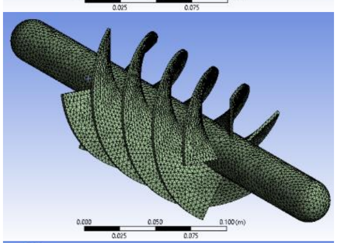
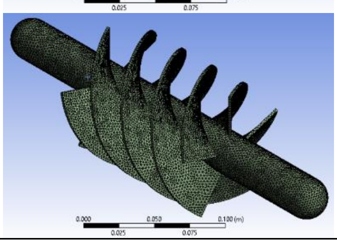
2.1. Mesh Sensitivity

Ansys CFX software was used in this research to carry out CFD modeling and simulation. Determining the shape and size of the mesh greatly influences the simulation results [13], so it is necessary to repeat it when selecting the mesh. Repetition is carried out until convergent results are obtained, especially on rotating objects such as turbines [14]. In this research, six repetitions were carried out by comparing the number of elements to the torque produced. The torque values obtained from the Ansys simulation were validated with experimental results in previous research [4].

Comparison of mesh shapes to obtain convergent results as well as the comparison of the number of elements to torque are presented in Table 2 and Fig. 3. A large number of elements indicates a small mesh size, the consequence is that the simulation time becomes longer [7], [14]. This is also a consideration in choosing an appropriate mesh size that does not overload the computer in the simulation process.

From Fig. 3 it can be seen that increasing the number of elements from 483049 to 697394 produces torque values that are not much different, a difference of 0.8 – 1.3% compared to laboratory tests [4]. So for a faster simulation with relatively accurate results, the mesh is chosen with the number of elements that are between the two or one of the two.

Table 2. Comparison between mesh and number of elements

Name	No. of Element
	313025
	375447
	407517
	430880
	483049
	697394

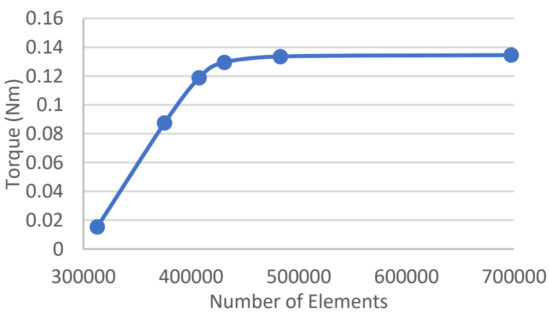


Figure 3. Relationship between the number of elements and torque

2.2. CFX Setup

The setup in Ansys consists of determining boundary conditions, selecting the turbulence model, and determining the type of simulation, steady-state or transient. In this research, a transient simulation was carried out to obtain the flow shape when the turbine rotates (Fig. 4). There are three domains created, namely water, outrigger and turbine can be seen in Fig. 5.

```
FLOW: Flow Analysis 1
  SOLUTION UNITS:
    Angle Units = [rad]
    Length Units = [m]
    Mass Units = [kg]
    Solid Angle Units = [sr]
    Temperature Units = [K]
    Time Units = [s]
  END
  ANALYSIS TYPE:
    Option = Transient
    EXTERNAL SOLVER COUPLING:
      Option = None
    END
    INITIAL TIME:
      Option = Automatic with Value
      Time = 0 [s]
    END
    TIME DURATION:
      Option = Total Time
      Total Time = 100 [s]
    END
    TIME STEPS:
      Option = Timesteps
      Timesteps = 1 [s]
    END
  END
```

Figure 4. Transient analysis setup

The boundary of the outrigger was set to 3L (3 x length of the outrigger) to x+, 4L to x-, 1L both to z+ and z-, also 1L to y+ and y-.

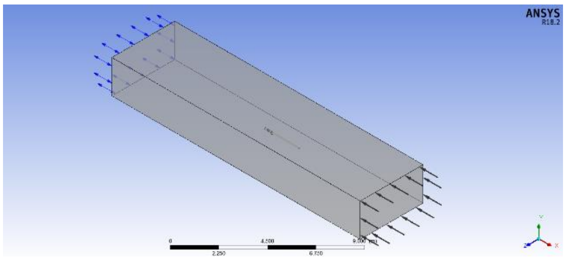


Figure 5. Domains of the setup

Water is set into a fluid domain with the Shear Stress Transport turbulence model. This turbulence model was chosen because of the large turbulence of water that occurs in the turbine and its surroundings. At the inlet, the velocity was set at 2.5 m/s, in line with laboratory experiments in previous research [4]. Meanwhile, the outlet section is set as an opening with a relative pressure of 1 atm.

The outriggers and turbine are set as immersed solid, but the outriggers do not move (stationary) while the turbine is set in the Rigid Body Solution (Fig. 6). This aims to ensure that the turbine can rotate on the x-axis when there is hydraulic power from water acting on the blades. In the Rigid Body Solution, the turbine weight and mass moment of inertia are entered for components xx, yy, zz, xy, xz and yz.

```
DOMAIN: outrigger
  Coord Frame = Coord 0
  Domain Type = Immersed Solid
  Location = B219
  BOUNDARY: outrigger Default
    Boundary Type = WALL
    Location = \
      F217.219,F218.219,F220.219,F221.219,F222.219,F223.219,F224.219,F225.2\
      19,F226.219,F227.219,F228.219,F229.219,F230.219,F231.219,F232.219,F23\
      3.219,F234.219,F235.219,F236.219,F237.219
  END
  DOMAIN MODELS:
    DOMAIN MOTION:
      Option = Stationary
    END
  END
END
DOMAIN: turbine
  Coord Frame = Coord 0
  Domain Type = Immersed Solid
  Location = B645
  BOUNDARY: turbine Default
    Boundary Type = WALL
    Location = \
      F646.645,F647.645,F648.645,F649.645,F650.645,F651.645,F652.645,F653.6\
      45,F654.645,F655.645,F656.645,F657.645,F658.645,F659.645,F660.645,F66\
      1.645,F662.645,F663.645,F664.645,F665.645,F666.645,F667.645,F668.645,\
      F669.645,F670.645,F671.645,F672.645,F673.645
  END
  DOMAIN MODELS:
    DOMAIN MOTION:
      Mass = 2 [kg]
      Option = Rigid Body Solution
      DYNAMICS:
        DEGREES OF FREEDOM:
          ROTATIONAL DEGREES OF FREEDOM:
            Option = X axis
          END
          TRANSLATIONAL DEGREES OF FREEDOM:
            Option = None
          END
        END
        GRAVITY:
          Gravity X Component = 0 [m s^-2]
          Gravity Y Component = -9.81 [m s^-2]
          Gravity Z Component = 0 [m s^-2]
          Option = Cartesian Components
        END
      END
      MASS MOMENT OF INERTIA:
```

Figure 6. Outtrigger and turbine setup

3. Results

From the simulation results on the transient type Ansys CFX, velocity contours of water around the turbine are obtained in the time range set in the setup section before, presented in Fig. 7. In addition, the angular velocity of the turbine (velocity in station frame) and the torque that occurs in the turbine can be obtained in the calculation menu, the result can be seen in Table 4.

From Fig. 7 it can be seen the difference in the shape of the flow through the outrigger and into the turbine as well as the pressure received by the turbine. In the first 60 seconds of the simulation, it is known that there is a large increase in pressure on the blade and shaft. This is influenced by the unstable incoming flow so the turbine rotation is not optimal. After 80 seconds of simulation, the turbine rotation has started to stabilize and the pressure on the blade has also become relatively more stable because the flow entering the outrigger has started to become constant.

With a water density of 1000 kg/m^3, gravitational acceleration of 9.81 m/s^2, turbine head of 0.015 m and area of the outrigger outlet is 0.0078 m^2, the hydraulic power and mechanical power which are then compared to obtain the efficiency of the Archimedes turbine installed in the outrigger by using equation 3, 4, 5 and 6 can be seen in Fig. 8. The relationship between the rotation of the turbine and mechanical power is presented in Fig. 9.

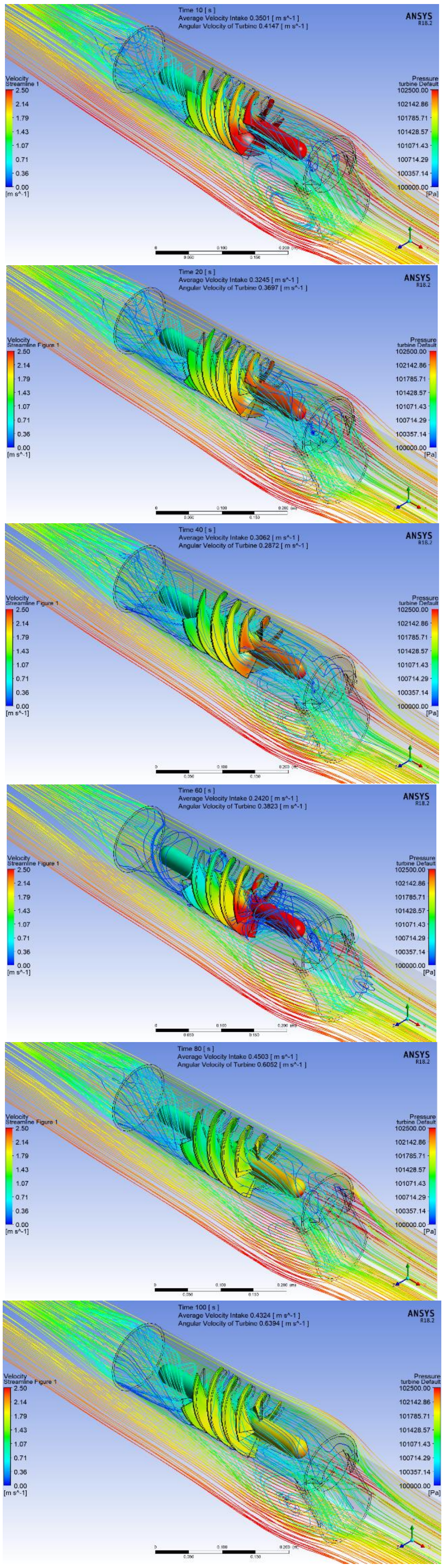


Figure 7. Velocity contour around the turbine and pressure contour in the turbine in various time ranges

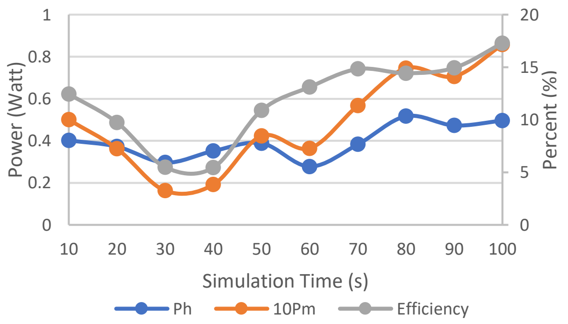


Figure 8. Hydraulic and mechanical power of the turbine

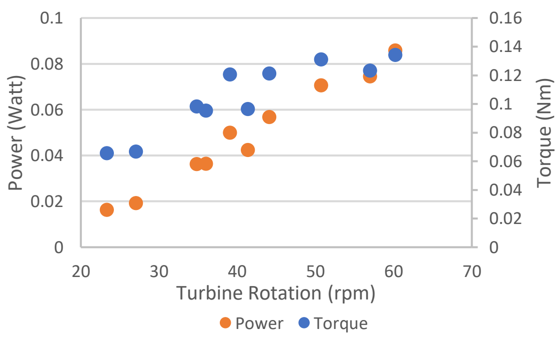


Figure 9. The relationship between turbine rotation and mechanical power

Fig. 8 shows that in the simulation of the Archimedes turbine on the outrigger of a fishing boat, mechanical power was obtained which had a different trend to hydraulic power, especially when the simulation lasted up to 60 seconds, after that both powers had relatively the same fluctuation trend. This condition is influenced by the unstable flow turbulence entering the turbine, as can be seen in Fig. 7. After the 60th second of the simulation, the incoming flow is relatively constant so that the increase in hydraulic power is comparable to the increase in mechanical power.

If viewed from the turbine rotation, the increase in mechanical power and torque in the turbine is directly proportional to the increase in turbine rotation. This is in line with the approach that can be taken using equations 4 and 5.

As a comparison, in Fig. 10 the flow contour around the outrigger is shown from the test results in the laboratory and the test results using Ansys. In Fig. 10, it can be seen that the flow turbulence that appears in the Ansys simulation results is not as complex as experiment in the laboratory, this is due to the graphical limitations of the device. However, in general the contour lines produced by Ansys depict similarities to water fluctuations that occur during laboratory experiment.

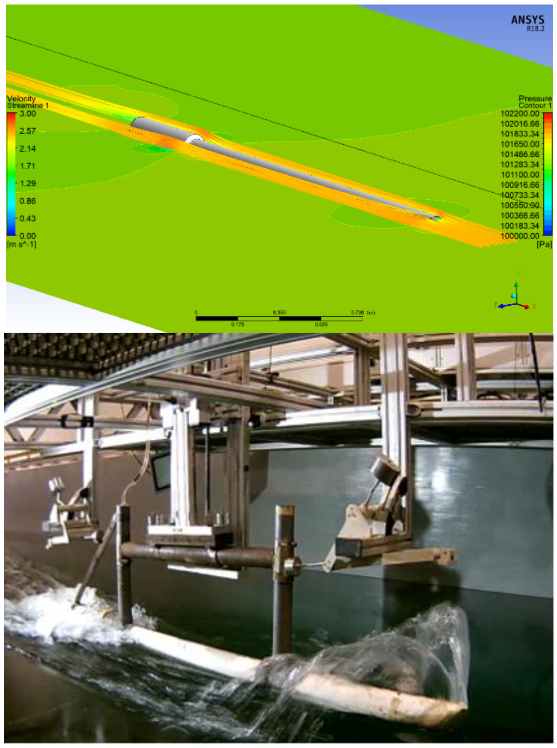


Figure 10. Difference between Ansys simulation and laboratory experiment

4. Conclusion

From the results of the simulation and analysis carried out, it can be concluded that the installation of an Archimedes screw turbine on a traditional fishing boat can be used as an alternative power generator, this is based on the turbine's ability to rotate and produce mechanical power and torque capable of turning the generator as was done in previous research.

The absence of an inclination angle results in a reduction in the turbine head value so that it directly affects the amount of hydraulic power provided by the water. This condition also causes small efficiency gains. It is necessary to modify the shape and size of the turbine to obtain more optimal power with better efficiency.

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