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NUMERICAL MODELING AND INVESTIGATION OF HYDROKINETIC TURBINE WITH ADDITIONAL STEERING BLADE USING CFD

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ABSTRACT

The rapid increase in global energy needs has generated a considerable attention to the generation of energy from renewable energy sources. Hydrokinetic turbines are a vertical axis type water turbine that is very simple and appropriate for remote areas. A hydrokinetic turbine has a good performance and is capable of producing considerable torque at high water speeds. The activity in this study is to model a small hydrokinetic turbine simulated with a CFD software, by varying the position of the turbine runner in each 5° runner rotation so as to obtain the pressure value between the two blades as an indicator of the force magnitude occurring or generated. In a previous study a vertical axis hydrokinetic turbine model was tested in the laboratory compared to the results with a simulated test with CFD. The laboratory test turbine performance result has a same or similar performance result calculate from the CFD simulation. From the simulation results it is seen that there are only two blades being pushed by the water flow. It is suggested to add a steering blade on the turbine output area, in order to increase the blade number to be pushed by the water flow rate. By attaching a steering blade on the output part of the turbine, the water prevents from leaving the turbine and deflected to push another blade, resulting in more water-boosting blades. To ensure that this step will produce a better result, the first step to do is simulating the turbine with a steering blade. The results obtained in every 5° runner position are that there is an increase in water pressure between the two blades. This phenomenon shows that there is an increase in the turbine performance. One of the simulation results is, at a runner position α = 20°,the water pressure between blade two and blade three rises from 8.15e + 009 Pa in the turbine without a steering blade, to 4.69e + 010 Pa in the turbine with a steering blade. While the water pressure between blade five and the blade six, that had a very low water pressure of 4.86e + 008 Pa, rose to 2.30e + 010 Pa, after being given a steering blade. This shows that the steering blade addition would give an additional water boost to some blades.

Keywords: hydrokinetic turbine, steering blade, runner position, computational fluid dynamic.

INTRODUCTION

Hydrokinetic turbine is a vertical axis type water turbine that has a simple construction and is capable of producing considerable torque at a high water velocity. This study was conducted by modeling a small hydrokinetic turbine simulated with CFD software. This research was conducted by varying the position of the runner turbine in each rotary motion of 5° so as to get the pressure value between the two blades as an indicator of the magnitude of the force that occurred or produced. In the study done by Soenoko, [1] experiments and simulation modeling (2D) have been done to determine the performance and flow evaluation on a hydrokinetic turbine. The type of hydrokinetic turbine observed is a vertical axial turbine and a curved blade. The turbine is placed in an open channel duct with a water flow rate and water speed in accordance with the size of its channel cross section. This study discusses a hydrokinetic turbine with a curved blade positioned on a water stream. From the simulation result, it was found that the water flow maximum only hit two blades at a certain runner angle position so that the efficiency of this turbine cannot be high.

In this further research it will be done an analysis by utilizing CFD software to see the water flow behavior. It is expected that from this water flow behavior in a hydrokinetic turbine, there will be an increase in the number of blades being pushed or hit by the water flow. In this study, the technology was adopted from a cross flow turbine construction [2], [3] and also combined with a Francis turbine construction technology [4] especially for the jet entry arc technology to steer the water passing through the cross flow turbine and the guide vanes guiding the water flow passing through the Francis turbine vanes. So in principle, a steering channel will be added on this simple hydrokinetic turbine to guide the water flow passes through a number of turbine blades.

This type of hydrokinetic turbine seems to have begun to be abandoned in relation to the amount of alternative energy that is considered easier to operate such as solar cell energy. But if looking closely, there is still a lot of unused energy even though it is still around us, as Rispiningtati [5] says about so many sources of water energy along the Brantas river network. It should be added that the Brantas river flow is still through some remote areas, so the smallest energy generated is still needed and useful in remote areas. Each energy generation (water, wind, solar energy etc.) has advantages and disadvantages. Therefore, any form and size of this power plant should continue to be developed and improved its performance.

As mentioned above, the performance of hydrokinetic turbine can be increased by adding a steering blade to the water output of the turbine, so that the water flow does not leave the runner turbine immediately, but it can provide an additional boost to the next blade so that overall there will be an additional boost of force on the runner turbine. The addition of steering blade in is based on the working principle of the cross flow turbine. In the intended cross flow turbine is the control device (Figure-1).

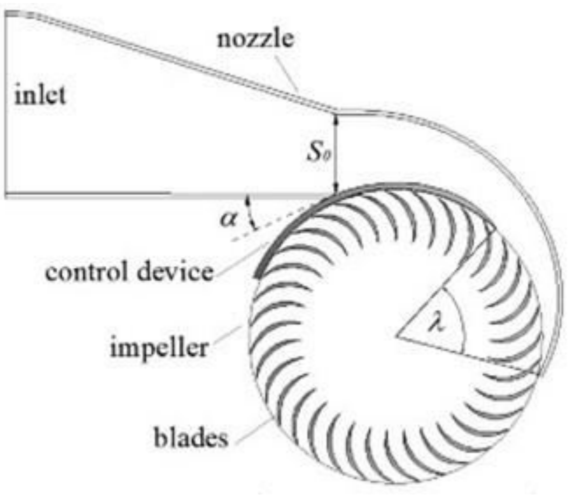

Figure-1. Cross flow turbine.

It should be kept in mind that this hydrokinetic turbine works in an open channel system, so the water flow rate is limited. The water flow rate has a maximum limit, because if the channel exceeds the ability to accommodate the water flow rate, then the water will overflow above the channel or overflow above the turbine. So that, there will be no additional energy if the water supply is given more than the maximum water flow rate. This principle is in accordance with the calculation of a maximize irrigation allocation mentioned by Rispiningtati [6]. The excess water flow that is not useful, may also give the effect of the river overflow (flooding).Based on some of these considerations, it is hoped that a hydrokinetic turbine design could reach a better performance based on this simulation research. So, if there are shortcomings and a poor design, then this hydrokinetic turbine design could be corrected and be optimized before being tested in the laboratory.

The most popular simple power plant for remote areas is the hydrokinetic vertical axis turbines, some prototypes have been tested under a laboratory conditions by Boedi [7], Monintja [8] and also by Lempoy [9], [10]. Soenoko has used CFD simulations to verify the results of laboratory tests that have been done before. Since the results of the laboratory tests compared with the CFD simulation results are very similar to the results, this CFD simulation can be done first before the laboratory test is done to obtain optimized hydrokinetic turbine design. So in this research, what was done is conducting a hydrokinetic turbine simulation activity by utilizing CFD software.

MATERIAL AND METHODS

The main steps taken in this research are three main stages, namely pre-processing, processing, and post processing. The pre-processing stage is the geometry making stage as shown in Figure-2, which is the making of runner hydrokinetic turbine geometry, which consists of a turbine runner equipped with turbine shaft, turbine drum and eight curved blade that is in accordance with the dimensions of the curved blade performed on the research then by Soenoko *et al.* [1].

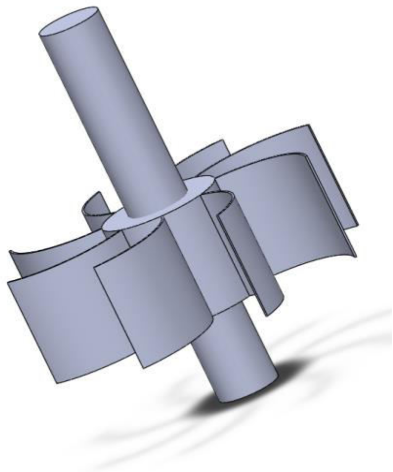

Figure-2. Hydrokinetic turbine runner.

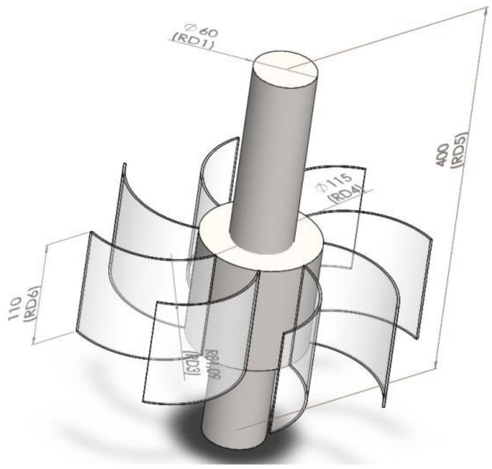

Figure-3. Hydrokinetic turbine runner dimension.

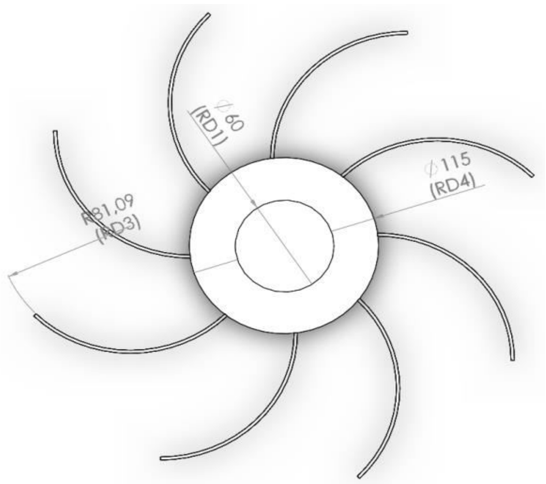

Figure-4. Hydrokinetic turbine runner dimension (Upper view).

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The next component that must be made in this research is a water duct that will be flooded where the hydrokinetic turbine should be placed. The open channel water duct is a representation of the water channel that will be used as a water channel where the hydrokinetic turbine will be positioned.

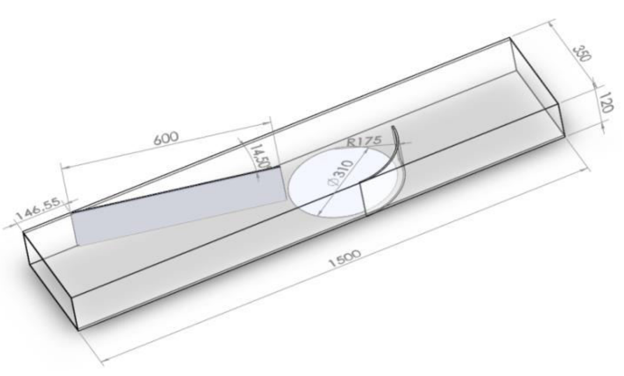

Figure-5. Water duct dimension.

This duct has dimensions of 1500 mm long, 120 mm high and 350 mm wide. In this duct also mounted boards as steering angle of α = 14.50°, this corresponds to the duct used in the fluid mechanics laboratory used for this hydrokinetic turbine test (Figure-5).The steering board is mounted on the wall of the water flow input portion of the duct. This steering board has a length of 600 mm. An additional steering blade is installed at the water outflow portion of the duct with an angle ω = 90° and a blade radius of 175 mm, as shown in Figure-6.

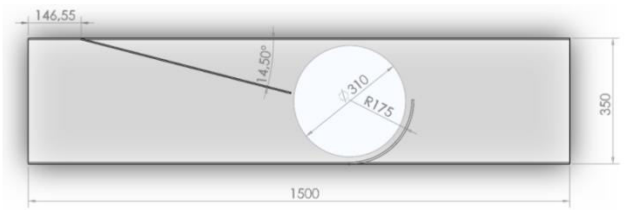

Figure-6. Water duct dimension upper view.

For the complete research installation, the Turbine Runner was placed on the water duct as see in Figure-7.

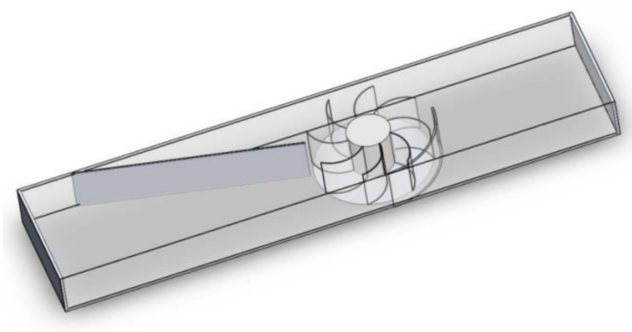

Figure-7. Research simulation installation.

Meshing

Producing meshes or better known as meshing is one step in pre-processing a simulation. Good for structural simulations using Finite Element Method (FEM), as well as CFD simulations that generally use Finite Volume Method (FVM). The mesh is useful to divide the model geometry into many elements which later be used by the solver to build the control volume. In some FEA (Finite Element Analysis) software, in mesh-making settings, fine and coarse options are found. Fine mesh will contain more cells to form a smoother model. Which one should be chosen for the simulation object. Fine mesh will of course produce more accurate calculations, since the equations are calculated at denser cell ranges. However, by making the mesh more tightly (which means that the more the number of cells are calculated) than the computing solver will be longer. With the use of more advanced software, meshing could be done with special software. This is useful for generating a good and proportional mesh (adjusted to the gradient parameter acting on the cell / node, e.g. CFD: speed gradient, density, pressure, etc.) There are several commonly used mesh types: Triangle (2D), Quadrilateral (2D), Tetrahedron Hexahedron, Pyramid, Prism / Wedge.

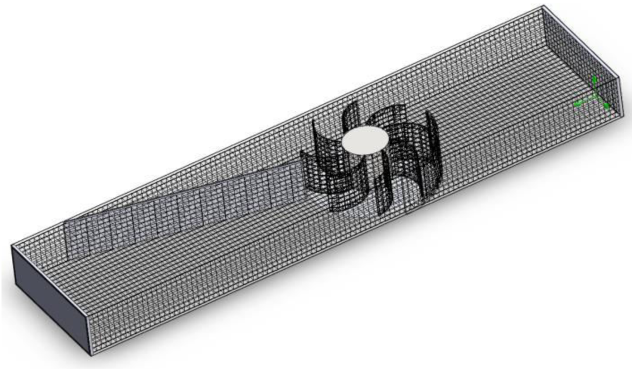

Figure-8. Meshing.

The mesh shape used in this simulation research is the Hexahedronmesh as seen in Figure-6 with automated mesh method and with a total cell count of 21,610. Fluid cells as much as 21,610 and fluid cell contacting solids of 7,950.

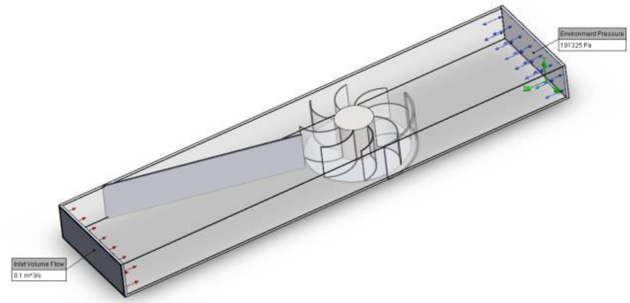

Figure-9. Hydrokinetic turbine boundary conditions.

The boundary condition used on the inlet is the velocity inlet free stream with a 0.1 m^3/s water flow rate, while at the outlet, a flow-split outlet was used with an environmental pressure of 101325 Pa and T = 293.2 K. On each blade and shaft a wall with rotational motion was used. The upper and lower boundaries are defined as a symmetry plane and at the confluence between two domains are defined as interfaces. The working fluid in this simulation is water with a density ρ = 1000 kg/m^3,and with a 8.90 × 10-4 Pa.s dynamic viscosity.

RESULT AND DISCUSSIONS

In the next few figures, the vertical pressure contour axis hydrokinetic turbine at a various runner turbine position with a 0.1 m/s water velocity would be shown. In these figures, it can be seen that the highest rotating speed of a water turbine occurs at a water speed of 0.1 m/s because the increase in water pressure is directly proportional to the force increase [11]. In the picture of the water pressure contour the increment of the runner position angle will increase the force. When the water turbine runner reaches a 45° rotation angle, the water pressure is the largest which cause the turbine to rotate better and more stable. The greater the force, the greater the torque it produces. At a runner angle rotation above 45°, a vortex begins to appear, which causes a decrease in pressure on the blade so that the runner speed would decrease too. The water turbine angle that has been through a 45° rotational angle has decreased the water pressure due to the influence of the vortex formed and the water velocity condition flowing in the downstream area is not as fast as in the upstream area. The next images show the vertical shaft water pressure contour of a hydrokinetic turbine, which will explain the comparison between the hydrokinetic turbine with a steering blade and the hydrokinetic turbine without a steering blade.

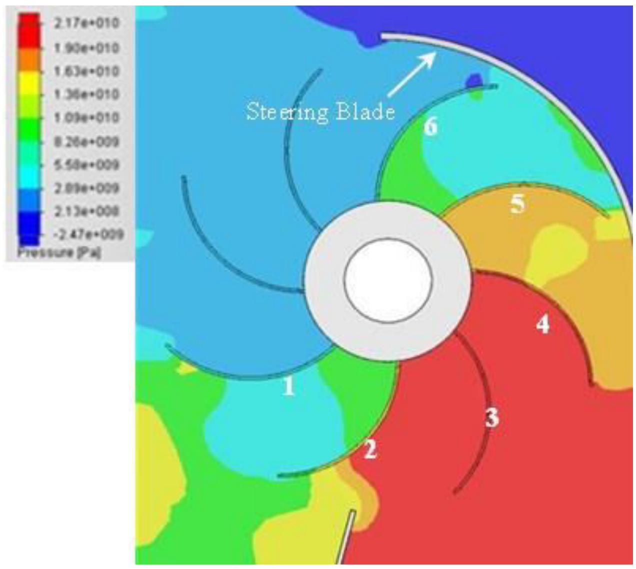

Figure-10. Pressure contour (Steering blade) (α = 0°).

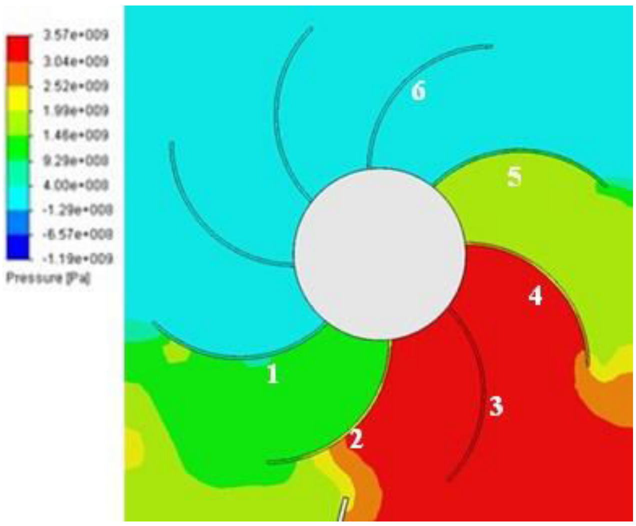

Figure-11. Pressure contour (α = 0°).

For a turbine runner on an α = 0° position, as seen in Figure-9, shows that the pressure between two blades on a steering blade vertical shaft hydrokinetic turbine is increased compared to a vertical shaft hydrokinetic turbine without a steering blade (Figure-10). This pressure increase indicates that there is an increase in

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force which results the turbine torque increase. The pressure between blade two and blade three on the turbine with a steering blade is 2,17e + 010 Pa, while in the turbine without a steering blade the water pressure is 3.57e + 009 Pa. So for the same blade position there is an increase in pressure on the turbine with a steering blade. While the lowest pressure occurs between blade five and blade six. In the turbine with a steering blade the pressure between blade five and blade six is 5.58e + 009 Pa, while the pressure on the turbine without a steering blade at the same runner position is 4.00e + 008 Pa. Thus the water pressure between the two blades on the turbine with the steering blade has a higher value than the turbine without a steering blade.

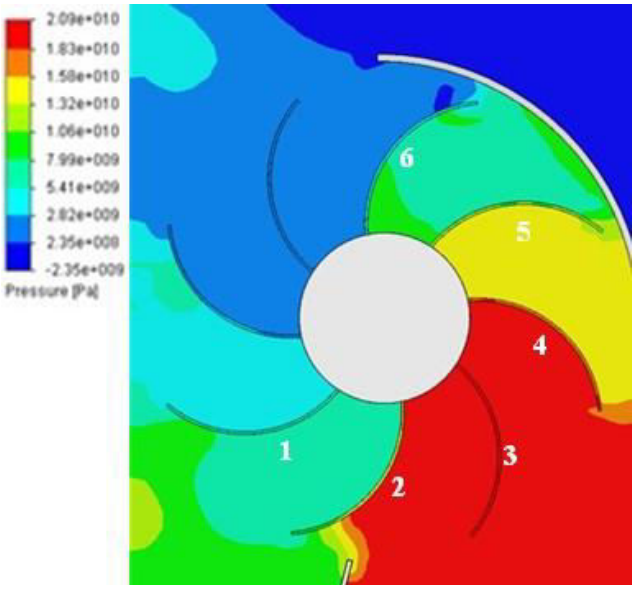

Figure-12. Pressure contour (Steering blade) (α = 5°).

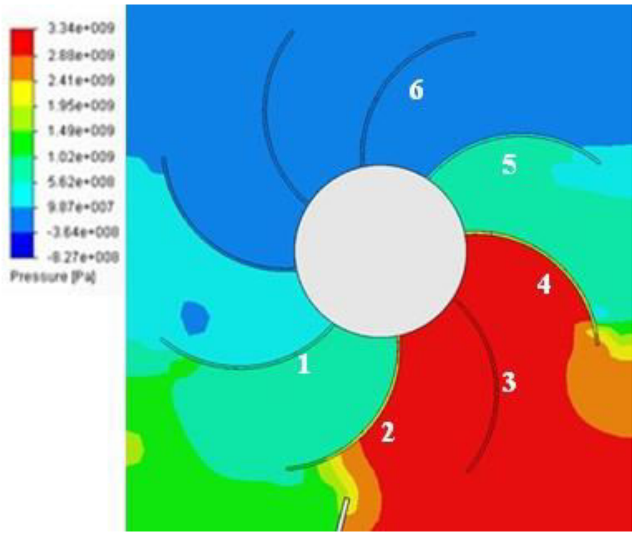

Figure-13. Pressure contour (α = 5°).

As in the discussion of the α = 0° runner position, in Figure-12, for the 5° run runner position, it appears that the pressure between the two blades on the steering blade vertical shaft hydrokinetic turbine is increased compared with the vertical shaft hydrokinetic turbine without a steering blade (Figure-13).

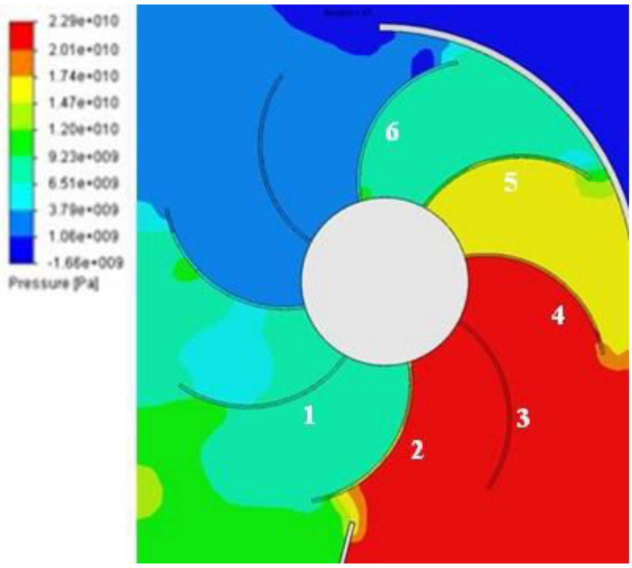

Figure-14. Pressure contour (Steering blade) (α = 10°).

The pressure between blade two and blade three on the turbine with a steering blade is 2.09e + 010 Pa, while on the turbine without a steering blade the water pressure is 3.34e + 009 Pa. So for the same blade position there is an increase in water pressure between the two blades on the turbine with a steering blade. While the lowest pressure that occurs between two blades is between blade five and blade six. In the turbine with a steering blade the pressure between blade five and blade six is 1.32e + 010 Pa, while the pressure on the turbine without a steering blade at the same runner position is 5.41e + 009 Pa. Similar to the pressure occurs on the 0°runner position, the water pressure between the two blades on the turbine with the steering blade has a higher water pressure value compared to the turbine without a steering blade.

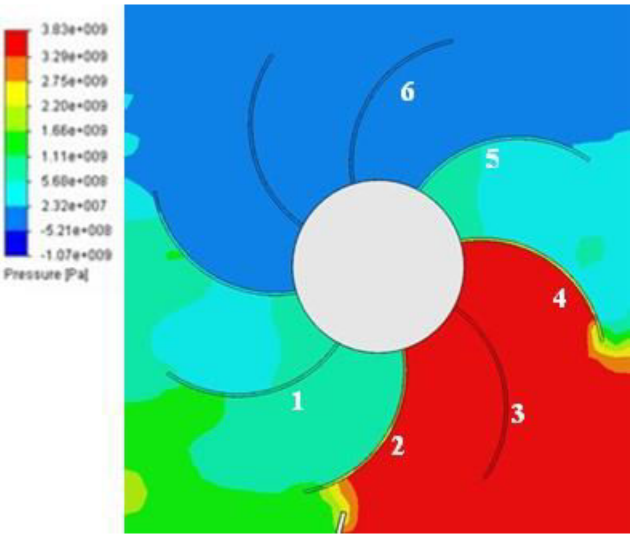

Figure-15. Pressure contour (α = 10°).

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Furthermore, for the 10° runner position as seen in Figure-14 it is also seen that the pressure between the two blades of the vertical shaft hydrokinetic turbine has a higher water pressure value than the vertical shaft hydrokinetic turbine without a steering blade (Figure-15). The pressure between blade two and blade three on the turbine with a steering blade is 2.29e + 010 Pa, while in the turbine without a steering blade the water pressure is 3.83e + 009 Pa.

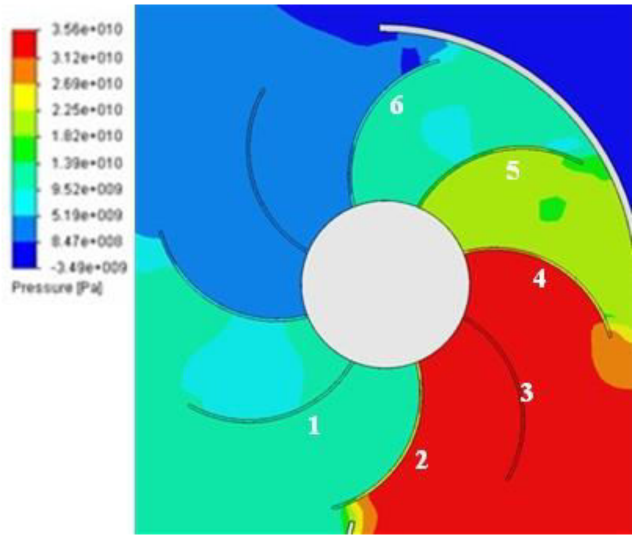

Figure-16. Pressure contour (Steering blade) (α = 15°).

It could be seen that on the same blade position there is an increase in water pressure on the turbine with a steering blade. The lowest pressure occurs between blade five and blade six. The water pressure between blade five and blade six, on the turbine with a steering blade is 1. 20e + 010 Pa, while the pressure on the turbine without a steering blade at the same runner position is 2,32e + 007 Pa. Compared with the other runner position, the water pressure on the turbine with a steering blade has a higher water pressure value than that on the turbine without a steering blade.

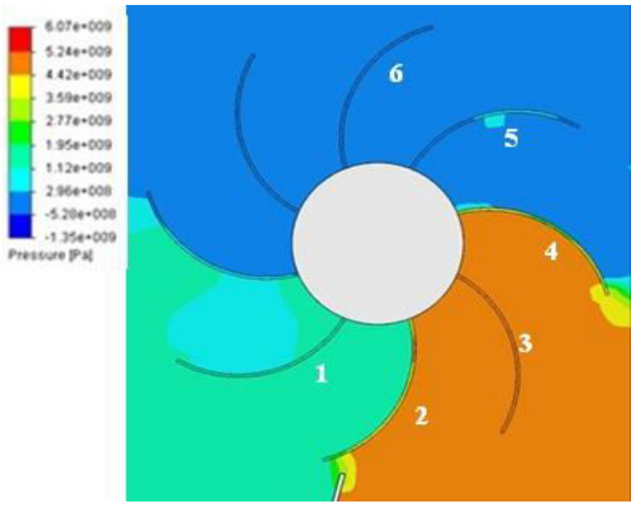

Figure-17. Pressure contour (α = 15°).

For the α = 15° runner position, there is also an increase in water pressure between the two blades as shown in Figure-16 and Figure-17. This water pressure increase indicates that there is a force increase, which resulting a turbine torque increase. The pressure between blade two and blade three on the turbine with a steering blade is 3.54e + 010 Pa, while on the turbine without a steering blade the water pressure value is 6.07e + 009 Pa.

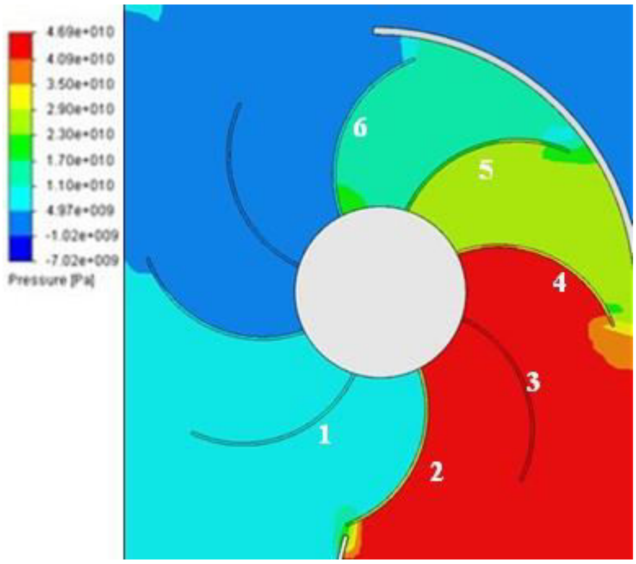

Figure-18. Pressure contour (Steering blade) (α = 20°)

So for the same blade position there is an increase in pressure on the turbine with a steering blade. While the lowest pressure occurs between blade five and blade six. In the turbine, with a steering blade, the pressure between blade five and blade six is 1.39e + 010 Pa, while the pressure on the turbine without a steering blade at the same runner position is 2.96e + 008 Pa. Thus the water pressure between the two blades on the turbine with the steering blade has a higher value than the turbine without steering blade.

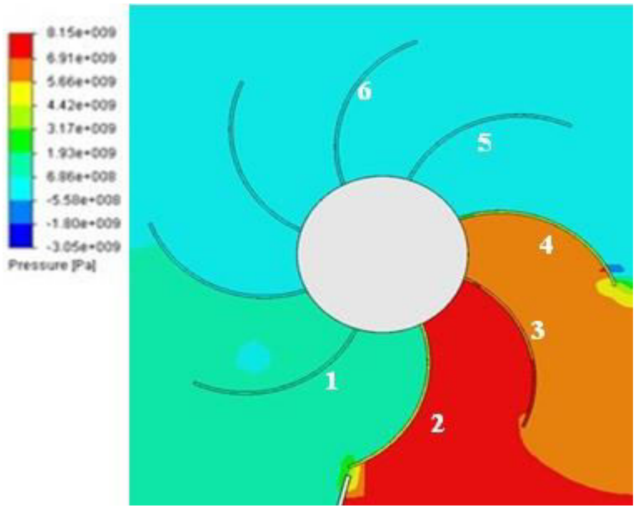

Figure-19. Pressure contour (α = 20°).

For the α = 20°runner position, as the runner position before, there is an increase in water pressure between the two blades as shown in Figure-18 and Figure-19. Again, this increase in water pressure indicates that there is a force increase, which resulting a turbine torque increase. The high water pressure, on the turbine with a steering blade, is between blade two and blade three with a pressure of 4.69e + 010 Pa, while in the turbine without a steering blade the water pressure value is 8.15e + 009 Pa.

On the same blade position there is an increase in pressure on the turbine with a steering blade. While the lowest pressure that occurs between two blades is between blade five and blade six. In the turbine with a steering blade, the pressure between blade five and blade six is 2.30e + 010Pa, while the pressure on the turbine without a steering blade at the same runner position is 4,86e + 008 Pa. Thus the water pressure between the two blades on the turbine with the steering blade has a higher value than the turbine without steering blade.

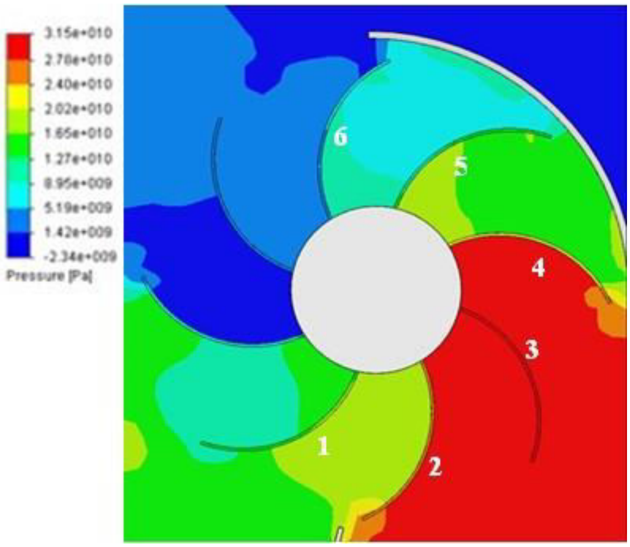

Figure-20 Pressure contour (Steering blade) (α = 25°).

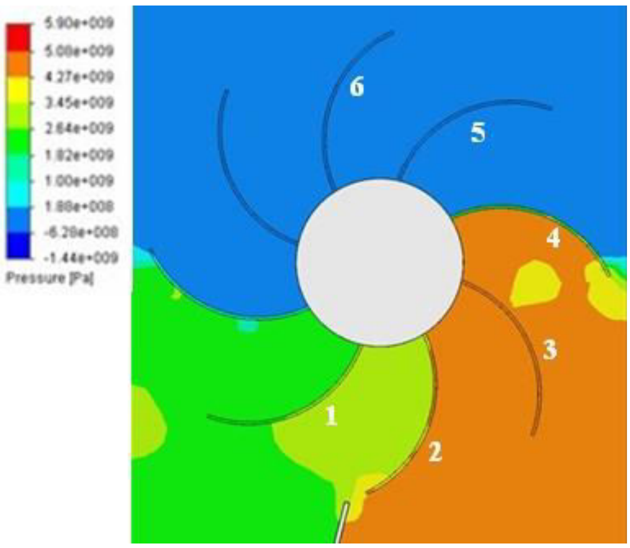

Figure-21. Pressure contour (α = 25°).

On the α = 25°runner position, the water pressure increase between two blades are shown in Figure-20 and Figure-21. The water pressure increase indicates that there is a force increase and would result a turbine torque increase. The pressure between blade two and blade three, on the turbine with a steering blade, is about 3.15e + 010 Pa, while the water pressure on the turbine without a steering blade is about 5.90e + 009 Pa. So for the same blade position there is an increase in pressure on the turbine with a steering blade. While the lowest pressure that occurs between two blades is between blade five and blade six. In the turbine with a steering blade the pressure between blade five and blade six is 8.95e + 009 Pa, while the water pressure on the turbine without a steering blade at the same runner position is 1.86e + 008 Pa. Thus the water pressure between the two blades on the turbine with the steering blade has a higher value than the turbine without a steering blade.

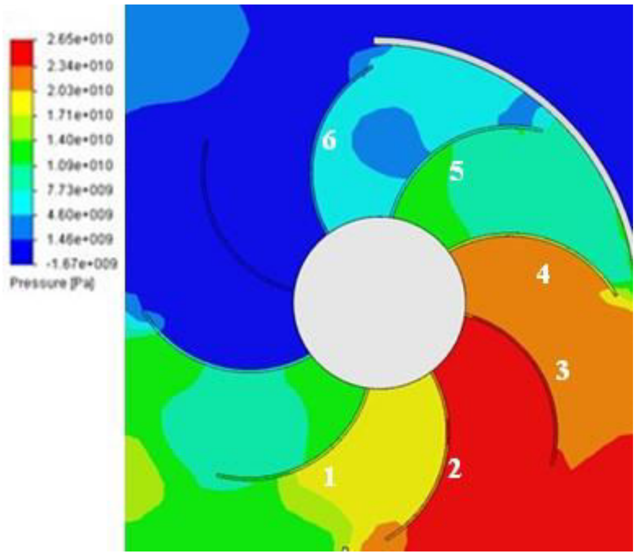

Figure-22. Pressure contour (Steering blade) (α = 30°)

From the observation of the α = 30° runner position, it is also seen that there is a water pressure increase between two blades as shown in Figure-21 and Figure-22, so there is an increase in the turbine torque. The pressure between blade two and blade three on the turbine with a steering blade is 2,65e + 010 Pa.

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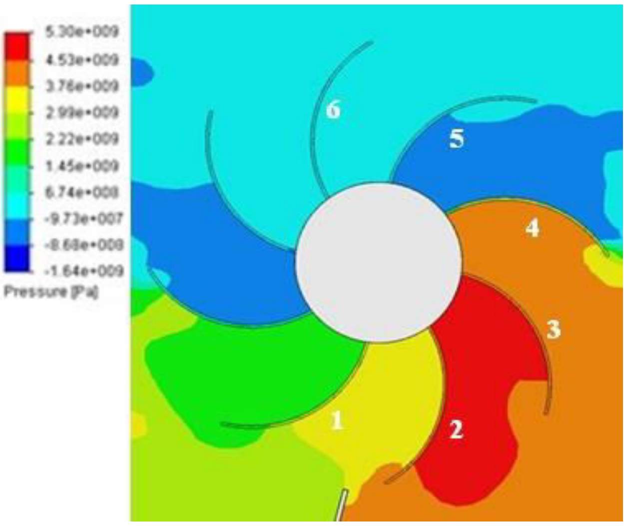

Figure-23. Pressure contour (α = 30°).

On the turbine without a steering blade, the water pressure value is 5.30e + 009 Pa. While the lowest pressure that occurs between blade five and blade six, for the turbine with a steering blade is 7.73e + 009 Pa, while for the turbine without a steering blade at the same runner position is 6.74e + 008 Pa.

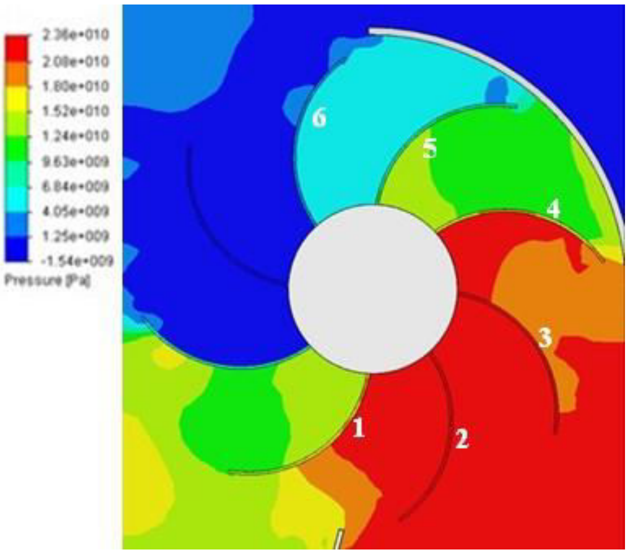

Figure-24. Pressure contour (Steering blade) (α = 35°).

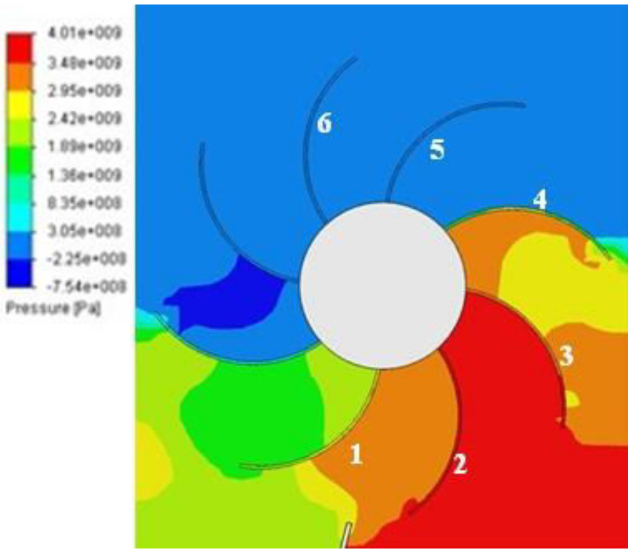

Figure-25. Pressure contour (α = 35°).

The next simulation result is the runner position at α = 35°. While as in the previous runner position water pressure also increases between the two blades as shown in Figures 24 and 25. The pressure between blade two and blade three on the turbine with a steering blade is 2,34e + 010 Pa, while on the turbine without a steering blade the water pressure value is 5.01e + 009 Pa. While the lowest pressure occurs between blade five and blade six. On the turbine with a steering blade the water pressure between blade five and blade six is 6.84e + 009 Pa, while the pressure on the turbine without a steering blade at the same position is 3.05e + 008 Pa. So, the water pressure on the turbine with the steering blade has a higher value than the turbine without a steering blade.

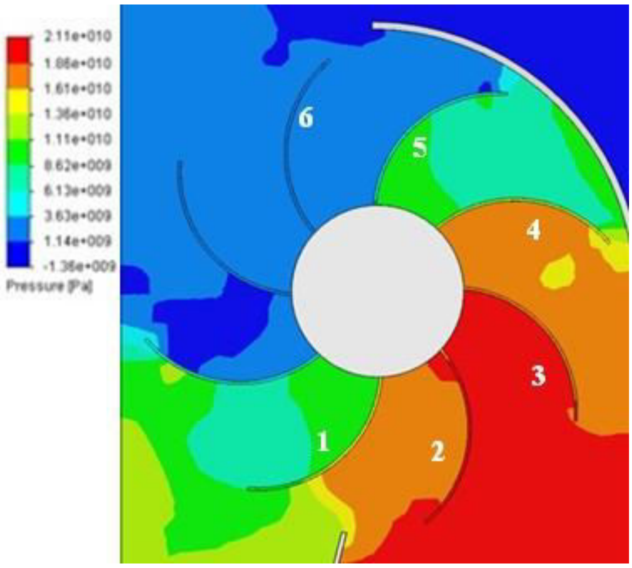

Figure-26. Pressure contour (Steering blade) (α = 40°).

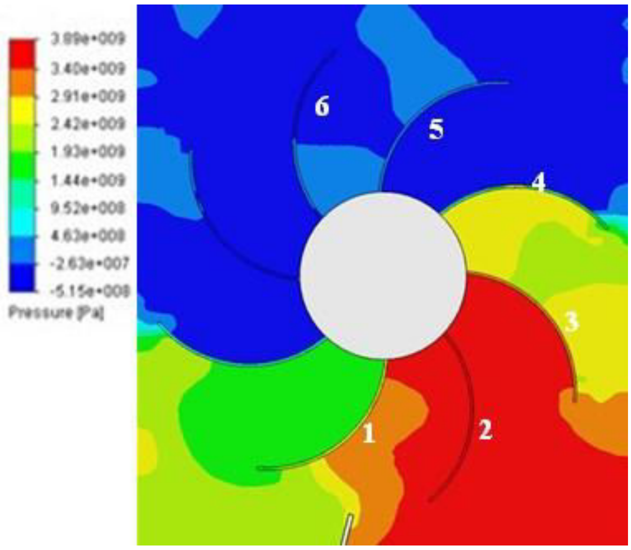

Figure-27. Pressure contour (α = 40°).

From the α = 40°runner position simulation result, it can be concluded that there is an increase of water pressure between two blades as shown in Figure-25 and Figure-26. So in this runner position there is also a turbine torque increase. The pressure between blade two and blade three on the turbine with a steering blade is 2,11e + 010 Pa, while on the turbine without a steering blade the water pressure value is 3.89e + 009 Pa. So, in general the water pressure increases in the turbine with a steering blade. The lowest pressure occurs between blade five and blade six. In the turbine with a steering blade the pressure between blade five and blade six is 3.63e + 009 Pa, while the pressure on the turbine without a steering blade at the same runner position is 4.62e + 008 Pa.

CONCLUSIONS

From a series of simulation results on the vertical shaft hydrokinetic turbine, it can be concluded that with the addition of a steering blade, the outflow of water outlet can be inhibited by the steering blade, not to leave the runner turbine immediately, but hit an additional blade and could provide an additional pressure energy on the turbine blade. As a result of the steering blade addition, it is evident that there is a considerable water pressure increase in the space between blade five and blade six. The water pressure between blade five and blade six is considered to be very low on the turbine without a steering blade. This is due to the flow of water that leaving the turbine area immediately after pushing blade one to blade five, so that the amount of water entering blade five and blade six is very small, even almost nothing. The small water entering blade five and blade six can be seen from the pressure contour indicated from the simulation result. The pressure between blade five and blade six for each runner angle position is about 4.00e + 008 Pa., to about 5.58e + 009 Pa. After the hydrokinetic turbine was given a steering blade, then the water pressure between blade five and blade six rose to about 1.29e + 010 Pa., which is an increase of 43 times greater. This means that the number of blades that get a boost from the water flow, after being given a steering blade, becomes four blades, compared with the turbine without a steering blade, which is only two blades. Another indication that an additional steering blade will increase the torque runner blade is the water pressure increase between blade one up to blade five. The average pressure increase is about five to six times. So, as overall, there is an increase in pressure between the turbine blades after the hydrokinetic turbine is given a steering blade. This result should still be proven by a laboratory test, because this result is obtained from a CFD simulation result.

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