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A Study on the Performance of the Split Reaction Water Turbine with Guide Ribs

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Abstract. The development of technologies that make use of renewable energy is of great significance presently. A new kind of turbine called Split Reaction Water Turbine (SRWT) using PVC pipes as material is a major contribution towards harnessing the energy potentials of small stream low head water resources. SRWTs of diameter to height ratio (D/H = 110 cm/160 cm) were tested at the MSU-IIT College of Engineering Fluid Engineering Laboratory. Data on volumetric flow and pressure head at the turbine inlet of the SRWT were recorded using National Instrument Data Processing System using LabView software. In later experiments, guide ribs were installed at the vane of the exit nozzles in order to determine the difference in the performance of the ribbed and the non-ribbed SRWT. Simulations of the running SRWT were conducted using SOLIDWORKS software. Results of the simulations aided in the thorough analyses of the data from the experimental runs. A comparison of data from the ribbed and non-ribbed SRWT shows that guide ribs were effective in directing the momentum of the exiting water to improve the speed of rotation. In this study, the increase in the speed of the Split Reaction Water Turbine was as much as 46%.

1. Introduction.

In developing countries like the Philippines, there are few fossil fuel resources and the effort towards an industrialized economy is hindered by the great need for cheap and reliable power. The correct solution to the growing energy demand is to develop renewable energy technologies. Research for turbine that can be operated to utilize small stream and low head water resources is a contribution to the development of renewable energy technologies. A new kind of reaction turbine, fabricated by splitting a PVC pipe, has a great potential in renewable energy development. The turbine is called Split Reaction Water Turbine (SRWT) [1,2].

2. Statement of the Objectives

The objectives of the study are:

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1. To investigate the effect of guide ribs in the vanes at the exit nozzles of the Split Reaction Water Turbine (SRWT);
2. To compare the performance of SRWT with guide ribs on the vanes with the Non-ribbed vanes SRWT;
3. To identify some parameters that influences the performance of SRWT.

3. Scope and Limitations

This study focused on the evaluation of the performance of SRWTs with and without guide ribs at the exit nozzles. Before fabricating the SRWT simulations of the running SRWT were conducted using SOLIDWORKS computer software.

As the objective of the study was to apply SRWTs in small stream low head water resources, the experimental rig used a pump that can deliver 2 liters per second at an average hydraulic head of 1.5 meters at the turbine inlet port. Thus, findings in this study are by no means complete but important parameters were identified, paving the way for better designed and fitted SRWT to operate at any given low flow and low head water stream.

There was only one SRWT diameter to height ratio (*i.e.* D/H = 110 cm/160 cm) that was investigated in this study.

4. Theoretical Considerations

The bases of this study are the basic theory in fluid mechanics and the accepted principles in fluid machinery.

The *continuity equation* in the non-conservative form, as applied to an infinitesimal mass of fluid moving through the flowfield is:

$$\frac{D\rho}{Dt} + \left(\rho \nabla \bullet V\right) = 0 \qquad (1)$$

where $\frac{D\rho}{Dt} = \frac{\partial \rho}{\partial t} + \left(V \bullet \nabla\right)\rho$ Substantial Derivative of ρ

and $V = u\vec{i} + v\vec{j} + w\vec{k}$ Velocity vector

For a constant density (ρ) equation (1) is expanded and the *momentum equations* for the *x, y and z* directions are:

In the ***x*-direction** only

$$\rho\frac{\partial u}{\partial t} - \frac{f_x}{\beta} + \left(\rho u\frac{\partial u}{\partial x} + \frac{\partial p_x}{\partial x}\right) + \left(\rho v\frac{\partial u}{\partial y} - \frac{\partial \tau_{yx}}{\partial y}\right) + \left(\rho w\frac{\partial u}{\partial z} - \frac{\partial \tau_{zx}}{\partial z}\right) = 0 \qquad (2)$$

In the ***y*-direction** only

$$\rho\frac{\partial v}{\partial t} - \frac{f_y}{\beta} + \left(\rho u\frac{\partial v}{\partial x} - \frac{\partial \tau_{xy}}{\partial x}\right) + \left(\rho v\frac{\partial v}{\partial y} + \frac{\partial p_y}{\partial y}\right) + \left(\rho w\frac{\partial v}{\partial z} - \frac{\partial \tau_{zy}}{\partial z}\right) = 0 \qquad (3)$$

In the ***z*-direction** only

$$\rho\frac{\partial w}{\partial t} - \frac{f_z}{\beta} + \left(\rho u\frac{\partial w}{\partial x} - \frac{\partial \tau_{xz}}{\partial x}\right) + \left(\rho v\frac{\partial w}{\partial y} - \frac{\partial \tau_{yz}}{\partial y}\right) + \left(\rho w\frac{\partial w}{\partial z} + \frac{\partial p_z}{\partial z}\right) = 0 \qquad (4)$$

where $f = f_x + f_y + f_z$ is the total body force

The momentum in ***z***-direction is converted to the momenta in ***x*** and ***y***-directions when the water hits the walls of the turbine. Thus, summing the momenta in the ***x*** and ***y***-directions:

$$\rho\left(\frac{\partial u}{\partial t} + \frac{\partial v}{\partial t}\right) + \left(\rho g\right) + \left(\rho u\frac{\partial u}{\partial x} + \frac{\partial p_x}{\partial x}\right) + \left(\rho u\frac{\partial v}{\partial x} - \frac{\partial \tau_{xy}}{\partial x}\right) +$$
$$\left(\rho v\frac{\partial u}{\partial y} - \frac{\partial \tau_{yx}}{\partial y}\right) + \left(\rho v\frac{\partial v}{\partial y} + \frac{\partial p_y}{\partial y}\right) = 0$$

(*5*)

where $f_x = 0$; (assuming no body force on the fluid along the *x*-direction)
$f_y = - mg$ (negative since the weight of the fluid is directed downward)

The momentum equation (5) shows that the total momentum is composed of the momenta along the *x* and *y* directions. The momentum along the *z*-direction adds to the momenta in the *x* and *y* directions.

Guide ribs placed at the exit nozzles of the vanes of SRWT would allow the optimum transfer of momentum from the water to the turbine. That is, the guide ribs placed along the *x*-direction will limit the movement of water along the *y*-direction. Further, the momentum due to the gravitational force along the *y*-direction can be redirected towards the *x*-direction. Thus, the scheme is an innovation to improve the non-ribbed vane Split Reaction Water Turbine developed at RMIT University, Melbourne, Australia [1, 2].

5. Design of SRWT

The result of simulating a running SRWT in SOLIDWORKS software indicated that there is counter impulse at the nozzles created by the exiting water. The impulse is due to water that impinges on the small area equivalent to two times the thickness of PVC pipe times the height of the turbine, see figure 1. To reduce the counter impulse, the lips of the nozzles were sharpened, see figure 2.

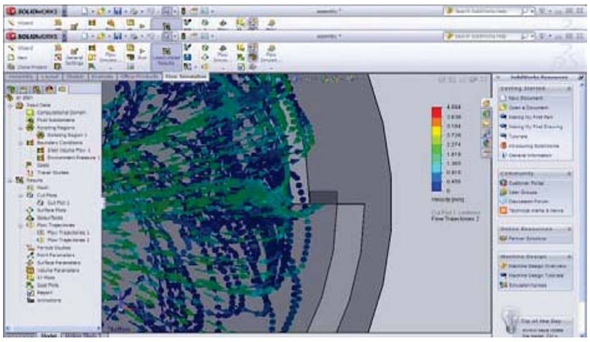

Figure 1. Top View of SRWT from Computer Simulation using SOLIDWORKS Software.

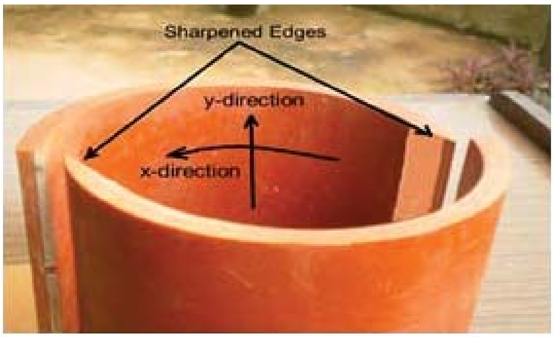

Figure 2. Sharpened Inner Lips of the Nozzles.

6. Experimental Test Rig and Test Procedure

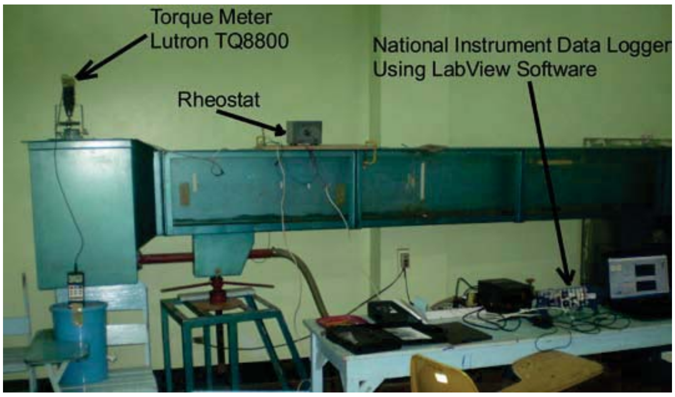

Figure 3. The Experimental Set-up.

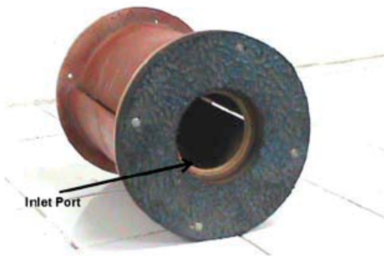

Figure 4. SRWT Without Guide Ribs.

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The SRWTs were tested in the Mechanical Engineering Fluids Laboratory using the Hydraulic Flume as the platform. The Hydraulic Flume is equipped with an electric pump that can deliver 2.0 liters/sec with a head of 1.5 meters to the SRWT. The SRWT was installed at one end of the Hydraulic Flume inside the water source tank and over it was the Lutron TQ8800 torque meter. Figure 3 is a photo of the experimental set-up. Water was introduced to the inlet port of SRWT located at its bottom as shown in figure 4.

The water jet caused the SRWT to rotate and the exiting water from the turbine falls to the bottom of the water source tank. Then it flows through the hydraulic flume back to the storage tank located below the hydraulic flume. Figure 6 shows the installed rotating Ribbed-SRWT inside the water source tank of the Hydraulic Flume.

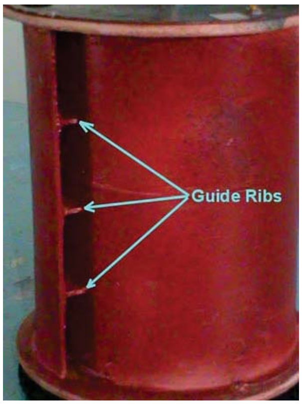

Figure 5. Photo of the SRWT With Guide Ribs Installed.

Figure 6. Photo of a running SRWT With Guide Ribs.

Figure 7. Photo of a static SRWT Without Guide Ribs.

The Hydraulic Flume is also equipped with a Venturi Meter of 44 mm diameter by 16 mm diameter at the throat. To control the flow of water through the Venturi Meter, a gate valve was installed before the Venturi Meter. Pressure difference at the Venturi Meter was measured using a differential pressure transducer and data were recorded through a National Instrument Data Processing System using LabView software. The logged data were recorded in a format that is Microsoft Excel compatible. Likewise, the pressures at the inlet of the SRWTs were recorded in the same manner.

The power outputs of the SRWTs were measured using Lutron TQ8800 torque meter and a non-contact digital tachometer manufactured by TT T-ECHNI-C. A prony brake was fabricated so as to adapt to the torque measuring procedure of the Lutron torque meter. Measuring the torque output of the SRWTs using Lutron TQ8800 and the digital tachometer combined, resulted to more accurate measurements of the actual power output of each SRWT. With this procedure, experimental runs were conducted to measure static torque with the prony brake absorbing the power output of the turbine.

The experiments on the SRWTs were executed by varying the volumetric flow into the turbine. This was carried out by opening and closing the gate valve located before the Venturi meter. In order to test the SRWTs uniformly on different volumetric flows the number of turns in opening and closing the valve were set. There were 7¾-turns from the closed position to the full open position of the valve. However, it was observed that the number of turns from closed to open do not result to the same volumetric flow if the number of turns were executed from open to closed.

Recorded data were analyzed using the basic principles of fluid mechanics and fluid machineries. In most cases where data were needed to complete the analyses, values were deduced from the recorded data using statistical tools. For example, since there is enormous data that were recorded for one gate valve opening, average values were used for analyses. Further, since the recorded data were discrete values and often values between them are needed for analysis, regression analyses were applied to the data.

7. Results and Discussion

Table 1. Representative results from running Non-ribbed-SRWT.

Non-Ribbed SRWT	Data Using Lutron TQ-8800								
Q (L/sec)	Hj (m)	Power (watts)	N (rev/min)	T (N-cm)	Ts (N-cm)	Dynamic Ø	Static Øs	Input Power Pi (watts)	Hydraulic Eff. (%)
1.87	1.42	0.118	105.0	1.08	7.7	0.27	0.28	25.98	0.46
1.85	1.42	0.277	97.9	2.70	7.6	0.27	0.27	25.70	1.08
1.86	1.41	0.385	91.9	4.00	7.6	0.28	0.28	25.84	1.49
1.84	1.41	0.336	87.3	3.68	7.6	0.27	0.27	25.54	1.32
1.72	1.43	0.267	94.4	2.70	7.7	0.25	0.25	24.17	1.10
1.43	1.38	0.189	93.9	1.93	6.7	0.21	0.21	19.29	0.98
0.45	0.83	0.003	32.2	0.10	1.5	0.09	0.09	3.68	0.09
1.08	1.34	0.037	93.1	0.38	5.8	0.16	0.16	14.16	0.26
1.88	1.43	0.222	93.3	2.28	7.8	0.28	0.28	26.35	0.84
1.88	1.42	0.345	100.7	3.28	7.7	0.28	0.28	26.25	1.32
1.88	1.43	0.229	97.3	2.25	7.8	0.28	0.28	26.24	0.87
0.43	1.06	0.065	66.6	0.93	2.6	0.07	0.07	4.51	1.43
1.82	1.41	0.114	104.1	1.05	7.5	0.27	0.27	25.19	0.45
1.72	1.39	0.102	102.6	0.95	7.1	0.26	0.26	23.43	0.44

Referring to tables 1 and 2, a comparison of the results from the experimental tests on the Non-ribbed and Ribbed-SRWTs is made. The results show that the Ribbed-SRWT had faster speeds at comparable flow-rate, Q and hydraulic head, H_j. Although, the differences in speeds of the two turbines are very pronounced, the torque T, of the Ribbed-SRWT was lower and uniform. The torques resulting from running the Non-ribbed-SRWT were averages of the minimum and maximum readings during one particular experimental run.

Static torque T_s, were obtained by tightening the contact of the prony brake and the turbine in such a way that the turbine was prevented from rotating. The torque reading from the torque meter was the maximum torque attainable by the turbine at such a given flow-rate Q and hydraulic head H_j. With dynamic torque T and static torque T_s known, the frictional losses can be calculated. However, since the objective of the study is to investigate the effect of guide ribs, frictional losses were not included in table 1 and table 2.

The differences in the static torques T_s, of the Non-ribbed and Ribbed SRWTs are indicative of the effect of guide ribs at the nozzles of the SRWT. Although the differences in the static discharge coefficients φ_s, of the Non-ribbed and Ribbed SRWTs are small it is noticeable that the Ribbed-SRWT had higher static discharge coefficients. This also indicates the effect of guide ribs at the nozzles of the SRWT. The same is noticeable with data from the two turbines on their dynamic discharge coefficients φ.

Table 2. Representative results from running Ribbed-SRWT.

Ribbed SRWT	Data Using Lutron TQ-8800								
Q (L/sec)	Hj (m)	Power (watts)	N (rev/min)	T (N-cm)	Ts (N-cm)	Dynamic Ø	Static Øs	Input Power Pi (watts)	Hydraulic Efficiency (%)
1.96	1.37	0.14	151.7	0.90	7.9	0.29	0.29	26.36	0.54
1.94	1.37	0.14	150.7	0.87	8.1	0.29	0.29	26.16	0.52
1.94	1.37	0.14	151.4	0.87	8.7	0.29	0.29	26.16	0.53
1.90	1.36	0.14	149.7	0.88	8.3	0.28	0.29	25.31	0.55
1.80	1.35	0.13	148.1	0.87	8.6	0.27	0.27	23.84	0.56
1.47	1.32	0.13	146.8	0.85	7.8	0.22	0.23	19.06	0.69
1.09	1.30	0.13	140.8	0.90	2.2	0.17	0.17	13.99	0.95
1.98	1.37	0.15	152.1	0.92	6.6	0.29	0.30	26.59	0.55
1.97	1.37	0.15	153.9	0.90	7.9	0.29	0.30	26.54	0.55
1.97	1.37	0.14	153.3	0.87	7.4	0.29	0.30	26.43	0.53
0.27	1.07	0.09	101.6	0.87	8.1	0.05	0.05	2.83	3.26
1.92	1.36	0.14	151.8	0.90	3.8	0.29	0.29	25.74	0.56
1.81	1.34	0.14	148.6	0.88	7.9	0.27	0.28	23.79	0.58

Data from table 1 and table 2 were regressed and the resulting equations plotted to produce figure 8 and figure 9. Figure 8 is a plot of Torque versus Speed (*T vs. N*) for both the Non-ribbed SRWT and the Ribbed-SRWT. The plot for the Non-ribbed-SRWT has a slope that is steeper than the slope of the plot for the Ribbed-SRWT. This indicates that a small increase in speed of the Non-ribbed-SRWT will result to a significant decrease in its torque output. This condition resulted to the erratic speed of the Non-ribbed SRWT. On the other hand, the plot of the Ribbed-SRWT has lesser slope. Thus, torque output of the Ribbed-SRWT was easily controlled by controlling its speed resulting to a smooth operation of the turbine.

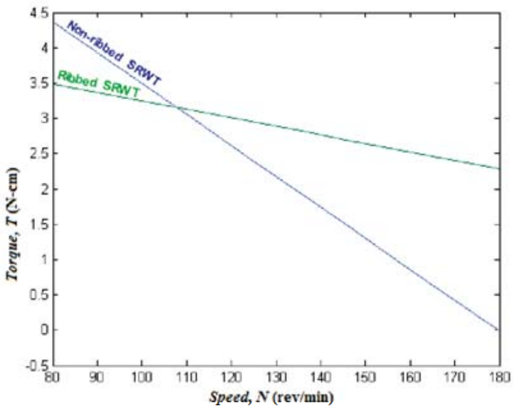

Figure 8. Plot of the Torque vs. Speed @ Q = 2 L/sec & H_j = 1.5 m.

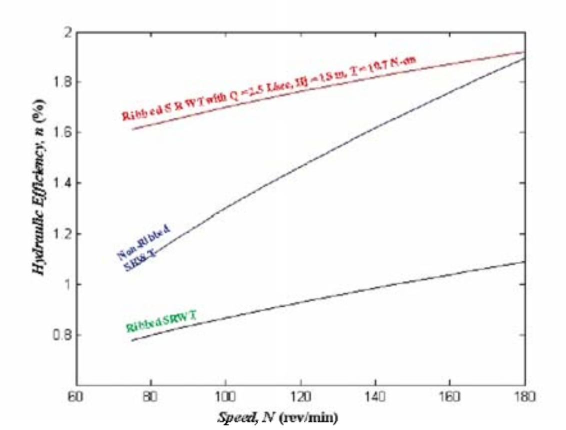

Figure 9. Plot of the Hydraulic Efficiency vs. Speed @ Q = 2 L/sec & H_j = 1.5 m.

Figure 8, shows clearly the effect of guide ribs in increasing the speed of the Ribbed-SRWT. At a torque of 3.0 *N-cm* the speed of the Ribbed-SRWT was 11% faster than the Non-ribbed-SRWT. On the other hand, at a torque of 2.4 *N-cm* the speed of the Ribbed-SRWT was 41% faster than the Non-ribbed-SRWT. At a much lower torque of 1.0 *N-cm* as shown in table 1 and table 2, the Ribbed-SRWT indicates faster speed than the Non-ribbed SRWT by as much as 46%.

Figure 9, shows that the Ribbed-SRWT attained lower hydraulic efficiencies compared to the Non-ribbed-SRWT. This is due to the requirement for hydraulic reaction turbines to have their runner passages completely filled with water [3]. In this case, the maximum flow-rate of 2 liters/sec of the circulating pump of the hydraulic flume was a limitation in attaining higher hydraulic efficiencies of the Ribbed-SRWT. Besides, at faster speeds of the Ribbed-SRWT the centrifugal effect contributed to demand higher flow-rate in order to completely fill its runner. Upon extrapolation from the data in Table 2 of the Ribbed-SRWT, higher efficiencies can be attained at a flow-rate Q = 2.5 liters/sec, hydraulic head H_j = 1.6 m resulting to a torque T = 10.7 N-cm. The plot is shown in figure 9.

8. Conclusions

The following conclusions were reached based on the data gathered during this study:

1. Guide ribs improved the coefficient of discharge from 0.27 to 0.29 as shown by the data from Non-ribbed SRWT listed in table 1 and from Ribbed-SRWT listed in table 2;
2. Guide ribs improved the speed of the SRWT by as much as 46% as shown by comparing the data from Non-ribbed SRWT listed in table 1 and from Ribbed-SRWT listed in table 2;
3. Installation of guide ribs at the exit nozzles although resulted to increase the speed of the turbine, required high flow-rate Q in order to completely fill the runner of the Ribbed-SRWT;
4. Sharpened lips at entrance to the nozzles of the SRWT reduced the impulse counter to the direction of the rotation of the SRWT. This conclusion is consistent with the results of the computer simulations using Solidworks software.

9. References

[1] Date A and Akbarzadeh A 2010 Design and Analysis of a Split Reaction Water Turbine *Renewable Energy* **35(9)** 1947-1955

[2] Date A and Akbarzadeh A August 2012 (http://www.SciRP.org/journal/sgre) Performance Investigation of a Simple Reaction Water Turbine for Power Generation from Low Head Micro Hydro Resources *Smart Grid and Renewable Energy* 239-245

[3] Daugherty, R L, Franzini J B and Finnemore E John 1989 Fluid Mechanics with Engineering Applications 507 McGraw-Hill Book Company, Singapore

[4] Lipson C and Sheth N 1979 Statistical Design of Engineering Experiments **(3rd Ed.)** McGraw-Hill Book Co., New York

[5] Sayers A T 1992 Hydraulic and Compressible Flow Turbomachines McGraw-Hill Book Company, Singapore