# DESIGN OF FLOATING WATER WHEEL FOR POWER GENERATION

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

AUGUST 2013

Specially dedicated to my parents and friends

# ACKNOWLEDGEMENT

First and foremost, I would like to express my greatest gratitude towards my supervisor, Dr. Md. Afendi bin M. Yusuf for the continuous guidance, encouragement, motivation and support in effort to complete this project.

Besides that, I would like to express my special thanks to Mr. Rizal and Mr. Azrin for providing the guideline and advice. Technicians and lab assistant in Center of Composites, Production Lab and Material Store also deserved special thanks for assisting and giving advice throughout the research.

Last but not least, all the commitments of my friends are gratefully appreciated and I would like to thank all who have helped me directly or indirectly in completing this project. Unfortunately, it is not possible to list all of them in this limited space.

# ABSTRACT

Floating water wheel could harvest energy from shallow flowing river to increase the potential of hydropower. Various types of water wheels have been studied by other researchers. However, the details of the design such as ridge/blade profile, number of ridges and submerged depth of floating water wheel have not been clearly established. In this research, experiments were carried out in an aquarium to study the optimum number of ridges, submerged depth and four different ridge profiles for a laboratory-scale floating water wheel. The results showed different ridge profiles and pitches and submerged depths contribute significant effects to the rotation of floating water wheel. The result of the experiment was used as reference for prototype design and fabrication. The prototype was tested in a river and successfully produced voltage from the flowing river. The experiment shows that the optimum number of ridges is 13, the best profile is thin flat ridge and maintaining the floating water wheel at certain submerged depth is important to its performance. The prototype concept is suitable for low head flow and varying water level. It is also portable, easily assembled and maintained and able to convert the kinetic energy of the water current into electrical energy.

# ABSTRAK

Kincir air terapung dapat menghasilkan tenaga dari aliran sungai yang cetek meningkatkan potensi untuk menjana kuasa hidro. Pelbagai jenis kincir air terapung telah dikaji oleh penyelidik di seluruh dunia. Walaubagaimanapun reka bentuk terperinci seperti profil rabung, bilangan rabung dan paras kedalaman kincir air terapung di dalam air belum dikaji dengan jelas. Dalam kajian ini, eksperimen telah dijalankan dalam akuarium untuk mengkaji bilangan rabung dan kedalaman paras kincir air yang optimum dan mengkaji empat profil rabung yang berbeza bagi kincir air terapung yang berskala kecil. Keputusan menunjukkan profil dan jarak antara rabung, dan kedalaman paras kincir air jelas memberi kesan yang ketara kepada putaran kincir air. Hasil daripada eksperimen ini telah digunakan sebagai rujukan untuk mereka bentuk dan fabrikasi sebuah prototaip kincir air. Prototaip ini telah diuji di sungai dan telah berjaya terapung serta menjana voltan daripada aliran sungai tersebut. Eksperimen ini telah menunjukkan bahawa bilangan rabung yang optimum ialah 13 dan profil terbaik ialah rabung rata yang nipis dan mengekalkan kincir air terapung pada kedalaman tertentu adalah penting untuk prestasi. Konsep prototaip ini sesuai untuk kelajuan aliran yang rendah dan berubah mengikut paras air. Ia juga mudah alih, senang dipasang dan diselengara dan dapat menukarkan tenaga kinetik daripada aliran air kepada tenaga elektrik.

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| | | |
|---|---|---|
| Cont. | - | Continue |
| N/A | - | Not available |
| etc. | - | Et cetera |
| rpm | - | Revolutions per minute |
| m | - | Meter |
| cm | - | Centimeter |
| mm | - | Millimeter |
| CAD | - | Computer-aided design |
| RM | - | Ringgit Malaysia |
| No. | - | Number |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $E_{in}$ | - | Input energy |
| $m$ | - | Mass |
| $g$ | - | Gravity =9.81m/s |
| $h$ | - | height |
| $v$ | - | Velocity |
| $H$ | - | Velocity head |
| $v_{max}$ | - | Maximum velocity |
| $y$ | - | Flow bed-normal distance measure upwards |
| $h$ | - | Flow depth |
| $1/m$ | - | Power-law exponent or index |
| $F_D$ | - | Drag force |
| $\rho$ | - | Density |
| $A$ | - | Summation of submerged ridges' frontal area |
| $C_D$ | - | Drag coefficient |
| $T$ | - | Torque |
| $R/r$ | - | Radius |
| $\theta$ | - | Angle |
| $W$ | - | Ridge's Width |

| | | |
|---|---|---|
| *N* | - | Total No. of Ridges |
| *I* | - | Ridge's number |
| L/h | - | Liter per hour |
| *P* | - | Power (watt) |
| Ω | - | Angular rotational speed (rad/s) |
| s | - | Second |
| *S* | - | Circular pitch |
| m/s | - | Meter per second |
| rad/s | - | Radian per second |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Hydropower

Renewable energy has imperatively become the alternative source of energy to replace fossil fuel as the major energy source, in light of the drastic depletion of fossil fuel due its application in most areas nowadays. In 2008, Sayigh [1] published a study about renewable energy in worldwide progress, which shows that among the six billion population, 1.8 billion have no electricity while 50 % of the inhabitants in Asia and Africa do not have reliable supply of electricity. The world population doubles itself every 50 years while energy demand doubles itself every 30 years and electricity demand doubles itself every 10 years [1]. There exists an urgent need to look into more reliable renewable energy source.

Hydropower is one of the renewable energy and is used in many countries to provide electricity in mega watt sizes. Similar to the present large-scale hydro power, mini-hydro and pico-hydro can also generate equivalent electrical power [1]. In view of the vast non-harvested energy in streams, rivers, irrigation raceway and et cetera, the small, mini and pico type of hydropower bears high potential and research on small scale hydropower will be inevitably increased in the near future.

## 1.2 Background Study

A hydropower harvester can be generally divided into two parts: its horizontal axis - fondly referred to as "hydro turbine", and its vertical axis - fondly referred to as "water wheel".

The turbine was introduced back in the early $19^{th}$ century, during which turbine manufacturing became a major industry and manufacturers came out with a wide range of catalogues to suit a variety of conditions and purposes [2]. Although the turbine ensures better performance than the water wheel, specific turbines could only be used in specific conditions, resulting in the need for designers to come out with different types of turbine. In order to harvest energy, the common hydro turbine needs to be fully submerged in the water. As such, its impact on the environment, particularly on aquatic life is much higher compared to the water wheel. Besides that, the complexity of turbines requires maintenance which is troublesome for normal users, especially those situated in rural areas.

The typical water wheel can be divided into three common categories, namely "overshot", "breast shot" and "undershot", providing advantages on both ecologic and economic costs [3]. Large-scale hydropower requires large dams and is extremely expensive in initial and construction cost due to the necessary construction of dams, reservoirs and canals meant to build up sufficient hydraulic head to regulate and direct the water flow towards the water wheel. However, the running costs are low. On the other hand, small scale type of hydropower can harvest energy in rivers and water channels even though these places are narrow or shallow. Its potential to rural areas and disaster areas is high especially the movable type of hydropower harvester. One of the movable hydropower harvesters is the floating type of undershot water wheel.

## 1.3 Problem Statement

Residents in rural areas are constantly facing insufficient electricity and electricity shortages. The presence of flowing rivers, mini-hydropower becomes an alternative solution. However, as most hydropower harvesters are fixed in position and do not vary with water level, these harvesters are frequently blocked by debris and require expertise for maintenance of the complex structure. Furthermore, the harvesters cannot operate in optimum performance where there is a change in water level, especially during the monsoon season. This research was carried out to study, design and develop a floating water wheel device which is portable and which varies with water level.

## 1.4 Objectives

The objective of this research is to design a floating water wheel device which varies with water level, is portable, requires simple maintenance and is able to convert kinetic energy of the water flow into electrical energy.

## 1.5 Scope and Limitations

This research was conducted to study floating water wheel performance in laboratory scale and in actual condition. Experiment study limits its coverage on four parameters only. Its main purpose is to investigate the effect of the parameters which are submerged depth, four different ridge/blade profiles and different number of ridges on the floating water wheel performance through experiment.

The study of the prototype only focuses on its functionability. The design of the prototype based on the optimum results from the experiment. Its aim is to prove the prototype design is workable in actual environment.

## 1.6 Significance of Study

Various types of water wheels have been studied by other researchers. However, the detailed designs such as ridge/blade profiles, number of ridges and submerged depth of floating water wheel have not yet been studied so far. The results obtained from the experiment here and the performance of the prototype could be used as a reference for further development. The further development will bring a large impact to rural areas in terms of electrical energy supply.

## 1.7 Methodology

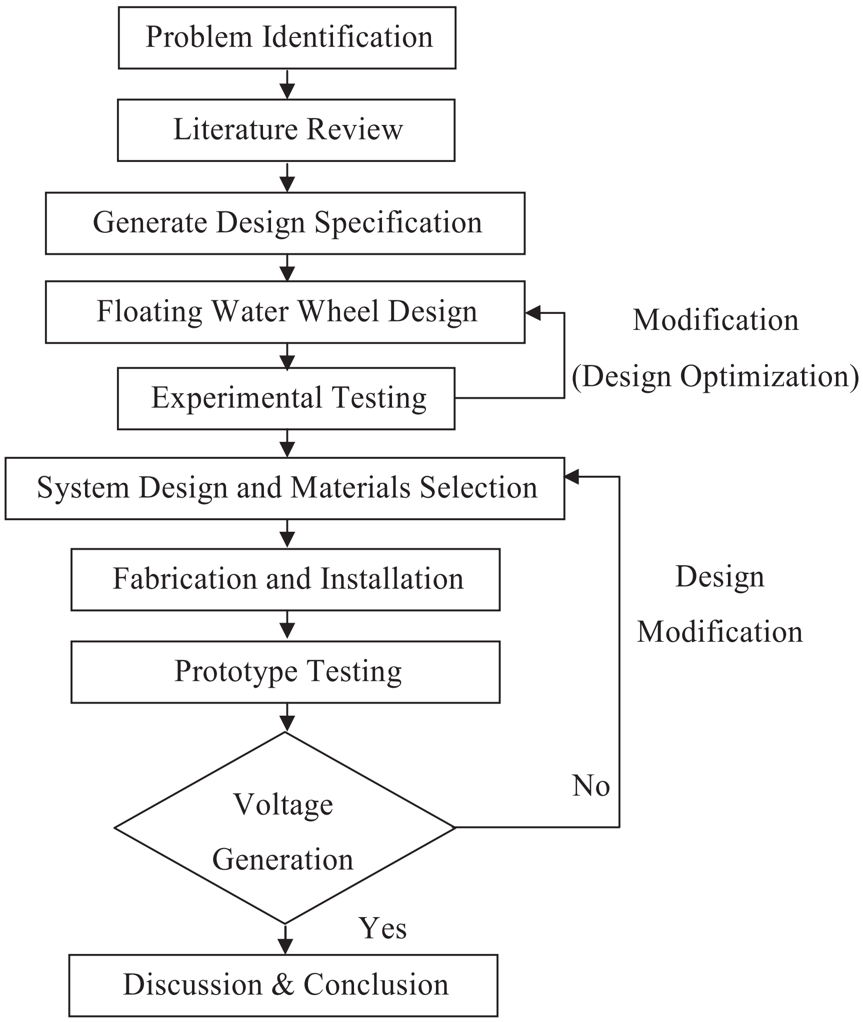


**Figure 1.1:** Design methodology flow chart.

As seen in Figure 1.1, the foremost step of this research is problem identification, as presented in Section 1.3. This is followed by a study on the evolution of undershot water wheel, reviews on several patented designs, a study on the concept and theory of the open flow water wheel and a study on water wheel calculation on certain parameters. The design advantages is then summarized from the literature review and abstracted to suit this research study. Subsequently, a series of experiments is carried out to study unestablished parameters of the floating water wheel, from which the results of a few parameters are analyzed to generate more detailed design criteria for the prototype. Finally, the prototype is fabricated and tested at the river side to show that the design idea is workable in slow flowing water. A counter rotating generator is then used to convert the output to electricity, and its voltage is recorded by the data logger to be followed by data analysis. Finally, the conclusion is drawn up and some recommendations are suggested at the end of the research.

## REFERENCES

1. Sayigh, A. Worldwide progress in renewable energy. *Renewable Energy*, 2009.

2. Smith, N.A.F. Water power. *History Today*, 1980. 30(3): 37-41.

3. Dubas, M. *A new ancient water mill: remembering former techniques mountains.* Springer Netherlands. 2008.

4. Reynolds, T.S. *History of the vertical water wheel, stronger than a hundred men.* The Johns Hopkins University Press. 1983.

5. Mays, L.W. A very brief history of hydraulic technology during antiquity. *Environmental Fluid Mechanics*, 2008. 8(5): 471-484.

6. Munro, J. *Industrial energy from water-mills in the European economy, fifth to eighteenth centuries: the limitations of power.* University of Toronto, Department of Economics. 2001.

7. Rao, J.S. *Water wheels history of rotating machinery dynamics.* Springer Netherlands. 2011.

8. Paz, E.B., Ceccarelli, M., Otero, J.E., Sanz, J.L.M., Paz, E.B., Otero, J.E. and Sanz, J.L.M. *Chinese inventions and machines: a brief illustrated history of machines and mechanisms.* Springer Netherlands. 2010.

9. Needham, J. *Science and civilisation in China.* Cambridge University Press. 1975.

10. Wang, Z. *Nong Shu.* Shang Wu Yin Shu Guan. 2009.

11. Denny, M. The efficiency of overshot and undershot waterwheels. *European Journal of Physics*, 2004. 25(2): 193-202.

12. Meier, A.B. *A brief history of perpetual motion.* Smashwords. 2011.

13. Bautista Paz, E., Ceccarelli, M., Echávarri Otero, J., Muñoz Sanz, J.L., Paz, E.B., Otero, J.E. and Sanz, J.L.M. *Medieval machines and mechanisms: a Brief illustrated history of machines and mechanisms.* Springer Netherlands. 2010.

14. Müller, G. and Kauppert, K. Performance characteristics of water wheels. *Journal of Hydraulic Research*, 2004. 42(5): 451-460.

15. Howard, R.A. A primer on waterwheels. *Bulletin of the Association for Preservation Technology*, 1983. 15(3): 27-33.

16. Müller, G. *Water wheels as a power source*. Access on 23 April 2013 [cited on 4 August 2013]. Available from: http://hmf.enseeiht.fr/travaux/CD0708/beiere/3/html/bi/3/fichiers/Muller_histo.pdf.

17. Müller, W. *The water wheels: technical drawings.* Veit & Comp. 1899.

18. Müller, W. *The water wheels.* Veit & Comp. 1939.

19. Anderson, J.S. *Improvement in water wheels.* U.S. Patent 96182. 1869.

20. Sory, A.W. *Improvement in current water-wheels.* U.S. Patent 98891. 1870.

21. Hensey, W. *Undershot water-wheel.* U.S. Patent 231041. 1880.

22. Fountain, L.D. and McDonald, J. *Water power.* U.S. Patent 244221. 1881.

23. Smythe, F.T. *Floating water elevator.* U.S. Patent 320184. 1885.

24. Garrison, C.M. *Means for utilizing the current force of running water.* U.S. Patent 273202. 1888.

25. Brown, H. *Water motor.* U.S. Patent 408075. 1889.

26. Bauer, J. *Water wheel.* U.S. Patent 414484. 1889.

27. Mather, A.C. *Water-power.* U.S. Patent 473941. 1892.

28. Highsmith, J.H. *Overshot or undershot wheel for propellin machinery.* U.S. Patent 578745. 1897.

29. Stickel, J. *Floating power-house.* U.S. Patent 603929. 1898.

30. Harris, C.E. *Water eleveator.* U.S. Patent 730260. 1903.

31. Gilliland, T.F. *Portable power dam.* U.S. Patent 757909. 1904.

32. Crow, W.H. *Portable power dam.* U.S. Patent 873845. 1907.

33. Jameson, N.W. *Water power appliance.* U.S. Patent 1029127. 1912.

34. Dale, J.T. *Current motor.* U.S. Patent 1263865. 1918.

35. Rennolds, P.J. *Tide-water power.* U.S. Patent 1333443. 1920.

36. Robinson, H.W. *Current motor.* U.S. Patent 1631647. 1927.

37. Miller, J.R. *Water wheel pump.* U.S. Patent 2694366. 1954.

38. Graden, L.E. *Water elevating wheel.* U.S. Patent 4280789. 1981.

39. Olson, M. *Apparatus for converting flow of water into electrical power.* U.S. Patent 4516033. 1985.

40. Kang, Chonju-si, H.S. and Chollabuk-do. *Runnning water waterwheel.* EP 0758052. 1995.

41. Dunn, E.D. *Movable and adjustable dam.* 5430332. 1995.

42. Lowery, M. *Hydro electric barrel generator.* U.K. Patent GB 0816315.6. 2008.

43. Griffin, R.A. *Hydraulic energy conveter.* U.S. Patent 2011/0179787 A1. 2011.

44. Booker, J.D., Mellor, P.H., Wrobel, R. and Drury, D. A compact, high efficiency contra-rotating generator suitable for wind turbines in the urban environment. *Renewable Energy*, 2010. 35(9): 2027-2033.

45. Shen, W.Z., Zakkam, V.A.K., Sørensen, J.N. and Appa, K. Analysis of counter-rotating wind turbines. *Journal of Physics: Conference Series*, 2007. 75(1): 1-9.

46. Müller, G. and Wolter, C. The breastshot waterwheel: design and model tests. *Proc. ICE Eng. Sustainability*, 2004. 157(4): 203-212.

47. Campbell, R.J. *Small hydro and low-head hydro power technologies and prospects.* Congress Research Service. 2010.

48. Wiemann, P., Müller, G. and Senior, J. Review of current developments in low head, small hydropower. *32nd IAHR Conference*. July 01-06, 2007. Venice, Italy: International Association of Hydraulic Engineering & Research. 2007. 1-10

49. Müller, G., Denchfield, S., Marth, R. and Shelmerdine, B. Stream wheels for applications in shallow and deep water. *32nd IAHR Conference*. July 01-06, 2007. Venice, Italy: International Association of Hydraulic Engineering & Research. 2007. 707-717

50. Chang, F.L. and Guan, S.S. Establishment of a quality scale (QFD) for creative product design service. *Management and Service Science (MASS), 2011 International Conference*. August 12-14, 2011. Wuhan: IEEE. 2011. 1-5

51. Chan, L.K. and Wu, M.L. Quality function deployment: a literature review. *European Journal of Operational Research*, 2002. 143(3): 463-497.

52. Wang, L., Lee, D.J., Liu, J.H., Chen, Z.Z., Kuo, Z.Y., Jang, H.Y., You, J.J., Tsai, J.T., Tsai, M.H., Lin, W.T., Lee, Y.J. and IEEE. *Installation and practical operation of the first micro hydro power system in Taiwan using irrigation water in an agriculture canal.* IEEE. 2008.

53. Raman, N. and Hussein, I. Reconnaissance study to identify micro hydro potential sites in Malaysia. *European Journal of Scientific Research*, 2010. 41(3): 354-372.

54. Cheng, N.S. Power-law index for velocity profiles in open channel flows. *Advances in Water Resources*, 2007. 30(8): 1775-1784.

55. Chen, C. Unified theory on power laws for flow resistance. *Journal of Hydraulic Engineering*, 1991. 117(3): 371-389.

56. Scott, J. *Drag of cylinders & cones*. Access on 24 April 2013 [cited on 24 April 2013]. Available from: http://www.aerospaceweb.org/question/aerodynamics/q0231.shtml.

57. Elghali, S.E.B., Balme, R., Le Saux, K., Benbouzid, M.E.H., Charpentier, J.F. and Hauville, F. A simulation model for the evaluation of the electrical power potential harnessed by a marine current turbine. *IEEE Journal of Oceanic Engineering*, 2007. 32(4): 786-797.