© 2014 IJEDR | Volume 2, Issue 2 | ISSN: 2321-9939

Hydrokinetic electric power generation system by oscillating hydrofoils

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***Abstract* - The system for converting kinetic energy from a fluid flow into mechanical energy, the method comprising the steps of Providing a turbine including first and second hydrofoils, each of the hydrofoils being able to move linearly in a heaving motion, and being able to oscillate about a span wise axis in a pitching motion. By coupling the heaving motions of the first and second hydrofoils to the pitching motions of the second and first hydrofoils respectively, with the pitch-heave motion phase being substantially equal to the inter-hydrofoil phase, the heaving motion of one of the hydrofoils thereby driving the pitching motion of the other hydrofoil. By transforming the heaving motion of the hydrofoils into a rotational movement of a shaft, with linear-to-rotary transmission means, the system can harness 261.8 watt power with 26.18% efficiency from water flowing with the velocity of 2 m/s.**

***Keywords* - Hydrofoil, Heaving, Pitching**

Nomenclature:

P_a Input power
b Foil span = AR*c
AR Aspect ratio
D Height of vertical extraction plane
c Chord length of hydrofoil
ρ Density of water
V Velocity of water
Re Reynolds number
ϑ Kinematic viscosity of water
C_L Coefficient of lift
α Angle of attack
t Maximum thickness as a fraction of the chord
x Position along the chord
y_t Half thickness at a given value of chord
θ Heaving angle
H_0 Maximum heaving amplitude
C Centre distance between two sprockets
p Pitch of chain
d Diameter of roller
Z No. of teeth on sprocket
M No. of links

1. INTRODUCTION

Conventionally most of the energy generation is based on fossil fuels, which are not renewable energy source. Due to increased use of energy, the requirement of non convectional energy sources is increased. To fulfill these requirements there is a need of harvesting energy from renewable energy sources.

In renewable energy sources, hydrokinetic turbines sector is growing fast with several new concepts and prototypes being developed in many countries. Most of them are using horizontal axis rotor or vertical axis rotor blades, but this type of turbine are not use full in shallow water sites. So the use of oscillating hydrofoils are an interesting alternative to rotating blades turbine. The concept offers an obvious advantage in shallow water sites due to its rectangular extraction plane, allowing possibility to scale up rated power by simply increasing the turbine hydrofoil span.

2. LITERATURE STUDY

The oldest prototype turbine oscillating wing listed in the literature, called "Wingmill", was developed in an experimental context at the University of Toronto by McKinney and DeLaurier in 1981. The purpose of this arrangement was to validate the analytical model developed to predict the performance of this type of turbine. This system was designed to operate with air as a working fluid. [2]

In 1999, Jones, Lindsey and Platzer have published work on the turbine wings oscillating at the Naval Postgraduate School in Monterey in the United States. Both systems have been analyzed, One with a wing and the other with two wings in tandem. The two mounting wings represents an evolution of a mounting flange, so that analysis will be presented for the case tandem.[2]

The tidal Stingray was built by the Engineering Company Ltd Business. The system has undergone testing in Scotland in 2002. The system carried out included one wing was aimed at eliciting 150 kilowatts of water flow. The wing had used imposing dimensions, a rope 3m, a total span of 15.4 m, and could make a heaving motion of a total height of 12 m. At the end of the project, EB abandoned the project due to economic non- viability.[2]

The company Pulse Generation has developed a turbine consists of oscillating wings two tandem wings 90 degrees out of phase . At the time of writing this paper, a 100kW tidal turbine is being tested in the estuary of the River Humber.[2]

The Australian company Bio Power Systems has developed a turbine oscillating wing based on the propulsion of some fish including tuna and shark. A project 250 kW pilot is in development (2009) to Flinders Island in Tasmania. The bio STREAM unit 20 m will be connected to the distribution network.[2]

The British company Pulse Generation Limited, one of the systems was presented in commercial systems section, has a British patent and a PCT filing to produce a mechanism to extracting power in a fluid. They protected by these patents mechanism similar to what was used for the system described case of pulse generation company.[2]

3. COMPONENTS

3.1 Hydrofoils

It is an underwater fin with a flat or curved winglike surface that is designed to lift a moving boat or ship by means of the reaction of its surface from the water through which it moves. Ships that use hydrofoils or foils are themselves called hydrofoils. Hydrofoils can be artificial, such as the rudder or keel on a boat, the diving planes on a submarine, a surfboard fin, or occur naturally, as with fish fins, the flippers of aquatic mammals, the wings of swimming seabirds.

3.2 Foil flipping mechanism

It consists of mainly two components. (1) Four bar chain mechanism (2) Chain sprocket assembly.

A four-bar linkage, also called a four-bar, is the simplest movable closed chain linkage. It consists of four bodies, called bars or links, connected in a loop by four joints. Generally, the joints are configured so the links move in parallel planes, and the assembly is called a planar four-bar linkage.

A sprocket or sprocket-wheel is a profiled wheel with teeth, cogs, or even sprockets that mesh with a chain, track or other perforated or indented material. A chain is a series of connected links which are typically made of metal. A chain may consist of two or more links.

3.3 Rocker crank mechanism

By this principle of inversion of a four bar chain, several useful mechanisms can be obtained. In a four bar linkage, if the shorter side link revolves and the other rocks (i.e., oscillates), it is called a crank-rocker mechanism. In this case, there is only a slight change, leave the smallest side and connect any of its adjacent side as the frame.Then (in figure) the smallest side 's' will have full 360 degree revolution while the other link adjacent to the frame has only oscillating motion (link p). This kind of mechanism is hence called a crank-lever mechanism or a crank-rocker mechanism or a rotary-oscillating converter.

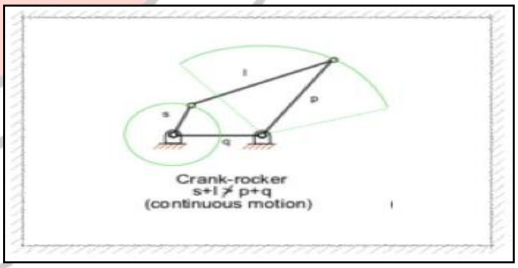

Figure 3.1 – Rocker crank mechanism

3.4 Crankshaft

The crankshaft, sometimes abbreviated to crank, is the part of an engine that translates reciprocating piston motion into rotational motion.

3.5 Gearbox

A gearbox is a mechanical method of transferring energy from one device to another and is used to increase torque while reducing speed. Each unit is made with a specific purpose in mind, and the gear ratio used is designed to provide the level of force required. This ratio is fixed and cannot be changed once the box is constructed. The only possible modification after the fact is an adjustment that allows the shaft speed to increase, along with a corresponding reduction in torque.

4. WORKING PRINCIPLE

Two hydrofoils are mounted with a horizontal frame in tandem configuration and frame is mounted with vertical frame at center. Both hydrofoils has angle of attack of same magnitude but in opposite direction, due to these forces on hydrofoils, they moves in opposite direction. At the maximum heaving angle, angle of attack is reversed and direction of forces also reversed. This cycle causes the oscillating motion of horizontal frame. This oscillation is converted into rotary motion of crank shaft with the use of four bar crank chain mechanism. Angle of attack is controlled by foil flipping mechanism which synchronizes the angle of attack and heaving angle with the help of the four bar crank chain mechanism and chain-sprocket assembly. Rotary motion of shaft is coupled with the electric generator through gearbox for desired speed and power generation.

5. DESIGN OF COMPONENTS

5.1 Design of Hydrofoils

Hydrofoil design is done with consideration of fixed input power, aspect ratio and water flow velocity.There will be stalling which causes the reduction in lift coefficient. At lower AR, there will be a reduction in lift curve slope. [10]

P_a = 1000 w
V = 2 m/s
AR = 7
D = 2.15*c [1]

$$P_a = \frac{1}{2}\rho V^3 bD \quad [3]$$

So, c = 128.85 mm

Different surface points of NACA 0015 hydrofoil can be generated using following equation.

$$y_t = \frac{t}{0.2} c \left[0.2969\sqrt{\frac{x}{c}} - 0.1260\left(\frac{x}{c}\right) - 0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 - 0.1015\left(\frac{x}{c}\right)^4\right] \quad [8]$$

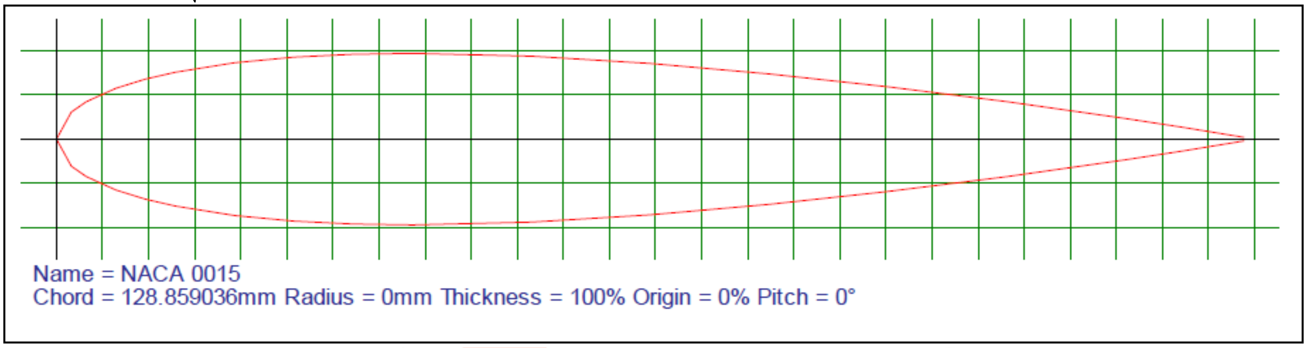

Figure 5.1-Cross section of hydrofoil [9]

5.2 Design of rocker crank mechanism

Maximum heaving angle = $\theta/2$
Heaving Amplitude = H_0 = c
Total Displacement = $2H_0$ = 2c [1]

By synthesis of the mechanism
L_1 = 347.9 mm = length of rocker
L_2= 1512.1 mm = length of coupler
L_3 = 128.8 mm = length of crank
L_4 = 1546.3 mm = length of column
ε = 1.07° [4][6]

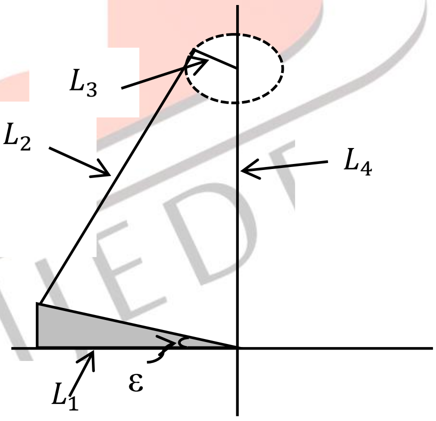

Figure 5.2-Rocker crank mechanism

5.3 Design of foil flipping mechanism

Foil flipping mechanism is combination of chain drive & four bar chain mechanism. Foil flipping results into oscillating of foils according to angular position of rocker on which foils are shafted. This mechanism helps to have maximum lifting force.

Two stage speed reduction is used because heaving of foil affects the pitching motion of the foil in case of single stage speed reduction with sprockets having different diameter.[5]

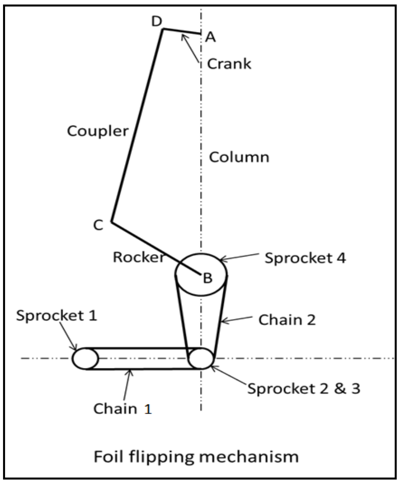

Figure 5.3-Foil flipping mechanism

Stage 1	Stage 2
Pitch, p = 9.525 mm	Pitch, p = 9.525 mm
Roller diameter, d_1 = 5.08 mm	Roller diameter, d_1 = 5.08 mm
Width, w = 4.76 mm	Width, w = 4.76 mm
Breaking stress = 7830 N	Breaking stress = 7830 N
Taking smaller sprockets;	Taking small & large sprockets;
No. of teeth on sprocket-1, Z_1 = 11	No. of teeth on sprocket-1, Z_3 = 11
No. of teeth on sprocket-2, Z_2 = 11	No. of teeth on sprocket-2, Z_4 = 44
Diameter of sprocket 1 = 33.8 mm	Diameter of sprocket 3 = 33.8 mm
Diameter of sprocket 2 = 33.8 mm	Diameter of sprocket 4 = 133.5 mm
No. of links M_1 = 84	No. of links M2 = 101
Exact centerdistance C_1 = 347.66 mm	Exact center distance C_2 = 346.42 mm
Length of chain = 800.1 mm	Length of chain = 962.025 mm

For four bar crank chain mechanism,
Length of rocker = 350 mm, Length of coupler =1153.32 mm
Length of crank = 112.5 mm, Length of column = 1200 mm

6. Results

Various values of C_L are obtained from the literature

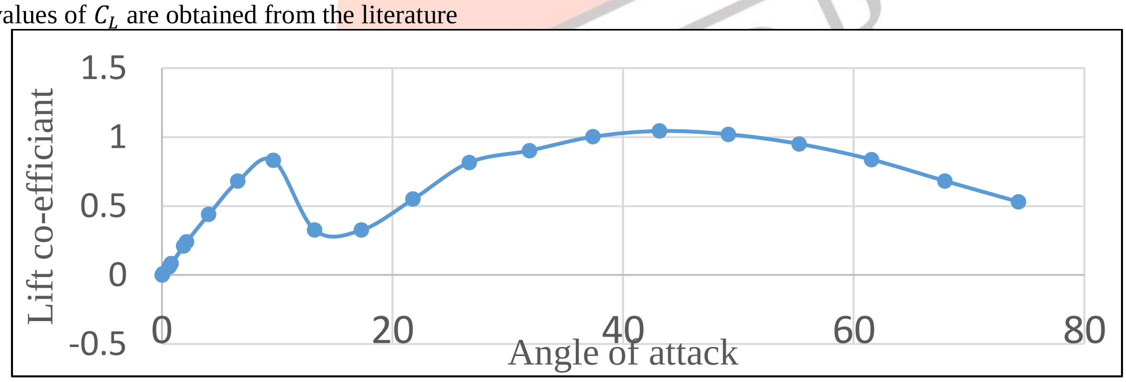

Figure 6.1 – Lift co-efficient vs. Angle of attack [7]

By analytical method of torque calculation,

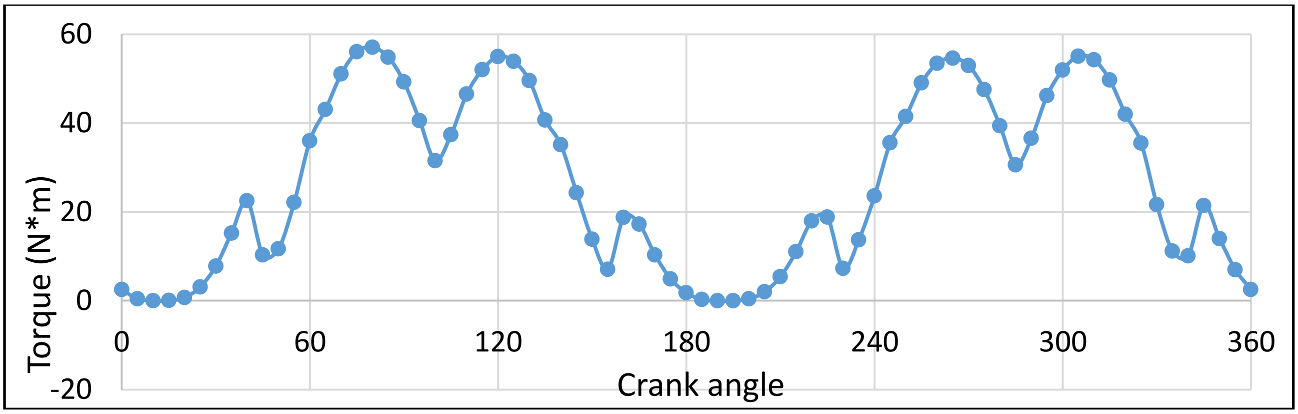

Figure 6.2 - Torque vs. crank angle

From calculations average torque = 26.88 N*m

7. SHAFT DESIGN

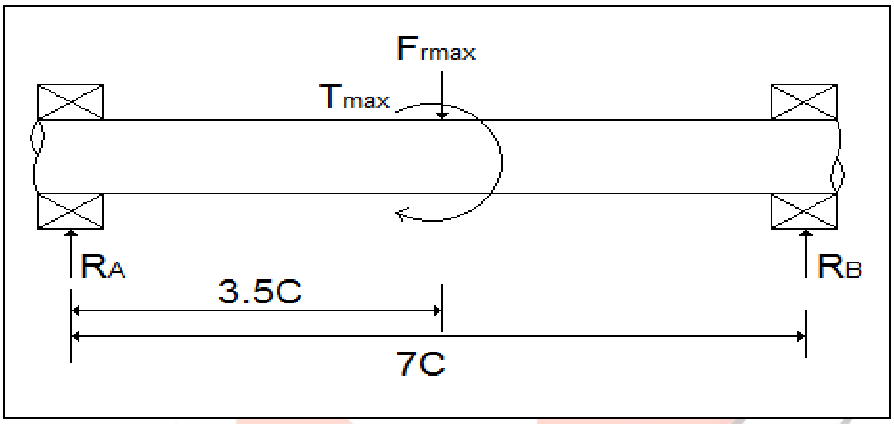

Figure 7.1 - Forces and reaction on shaft

By considering modified Goodman diagram,

Diameter of shaft = 18.49 mm [5]

8. GEAR RATIO SELECTION

By consideration of strouhal number and reduced frequency

Strouhal number, St = $\frac{2kh_0}{\pi c}$ [11]

Reduced frequency, K = $\frac{2\pi f c}{2V}$

So, Strouhal number, St = $\frac{2fc}{V}$

Speed of the shaft = 93.75 rpm

The general required rated speed for permanent magnet alternator is around 450 rpm

Two stage gear reduction is used,

Gear ratio = $^{93.75}/_{450} = {}^{1}/_{4.8} = {}^{1}/_{2} \times {}^{1}/_{2.4}$

Power on output shaft = 261.84 w

Efficiency of system = 26.18%

REFERENCES

[1] Kinsey T., Dumas G., Lalande G., Ruel J., Mehut A., Viarouge P., Lemay J., Jean Y. "Prototype Testing of a Hydrokinetic Turbine Based on Oscillating Hydrofoils." Renewable energy,ELSEVIER:2010

[2] D.A. Read, F.S. Hover, M.S. Triantafyllou "Forces on oscillating foils for propulsion and maneuvering." Journal of fluid and structures. www.elsevier.nl/locate/jnlabr/yjfls

[3] Fluid mechanics: Fundamentals and applications by- Y. A. Cengel -Tata McGraw Hill Publication

[4] Theory of machines by- R.S.Khurmi - S.Chand Publication

[5] Machine Design-I by- R.B.Patil – Techmax Publication

[6] Theory of machines by- S.S.Rattan - Tata McGraw Hill Publication
[7] Sandia national laboratories energy report (For, Lift Coefficient-C_L)
[8] An Introduction to Theoretical and Computational Aerodynamics - Jack Moran
[9] www.airfoiltools.com
[10] www.propdesigner.co.uk
[11] hmf.enseeiht.fr