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# Design Of Water Wheel For Micropowergeneration With Supercritical Inflow

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**Abstract:**

Hhydropower has always been recognised as clean and cheap source of power. Various sectors are facing a problem of power crunch and hence the micropower generation is becoming popular these days. In this regard, various attempts are made to generate power with the help of continuous subcritical flow of water available in canals. Present study proposes a new technique of micro power generation with supercritical inflow at the foot of the sluice gate in canals. As no literature is available, it was decided to design a water wheel which can give maximum output in the form of rpm speed and torque for above mentioned inflow conditions. At initial stage, the studies are carried out in CFD with various wheel designs (i.e. with different geometries of vanes attached on the periphery of wheel). At length, it is decided to physically test the performance of the best wheel suggested by CFD studies. Accordingly the tests are carried out in 0.3m wide and 8 m long tilting flume. The results obtained are found to be satisfactory and presented herein.

**Keyword:** Canal, Sluice gates, Supercritical flow, Micro power, CFD.



## INTRODUCTION

Hydropower is one of the cheapest and clean source of energy which can be obtained by different techniques. Day by day requirement of power increases which turns into facing scarcity of it. Various attempts are made to obtain power from continuous subcritical flow, [1]. Turbines can be used in case of availability of sufficient head at upstream of turbine. This study of generation of power at the canal gates is evolved from the industrial requirement of electricity for the instruments used for the canal automation. Monitoring and transmission equipments require electricity which can be obtained at the gate itself using proposed technique. This study proposes generation of power with small head and supercritical flow conditions at the upstream of the mechanism. Basic concept is based on the traditional waterwheel with vanes fitted at the periphery of the circular wheel. Geometry and angle of vanes is decided to get maximum force of water on the vanes.

## 2. METHODOLOGY:

### 2.1 Study of super critical flow at canal gate:

The supercritical flow is observed just downstream of the sluice gates. The energy of the water released from the gate should be dissipated in order to protect the canal geometry in the downstream from the damage. The properties of the supercritical flow are observed during this study. The depth of water varies according to the gate opening while velocity varies from 2 m/s to 4 m/s as per C. Penche [2].

### 2.2 Concept of water wheel:

Overshot and undershot wheels are mostly used for the power generation. Overshot wheel has more efficiency of 80% than that of undershot wheel with 60% [3]. Since fall is not available overshot wheel is eliminated and the study is carried over the undershot wheel. According to Dr. G. Muller [4] undershot wheel is used for the head around 1.2-2.3 m and velocity of 3 m/s. Payback time for the wheel is 13-14 years with life of 30 years.

### 2.3 Design of vanes:

Vane geometry should be such that it will provide maximum rotations to the wheel with minimum or nil backflow of water. Simulation was done using CFD software with vane in static condition. Force on thevane was found out for different water levels and vane submergence. Vane geometry was varied from flat to curve. Backflow conditions are also observed in the software.

### 2.4Simulation of vanes by CFD testing:

CFD is the tool used for the simulation of real conditions by computer based programming. Different conditions of flow, geometric objects and channel geometry can be tested in CFD. To design and obtain the best suitable geometry of vane different conditions are simulated in CFD. Channel size is taken as dimensions of tilting flume from Fluid Mechanics laboratory where the whole experimentation has been carried out. Following parameters of channel from table 1are used for the simulation in CFD for the determination of vane geometry,

**Table 1: Parameters of channel for CFD**

| | | | |
|---|---|---|---|
| 1 | Length | 1 | m |
| 2 | Width | 0.3 | m |
| 3 | Depth | 0.3 | m |
| 4 | Gate opening at inlet | 0.05 | m |
| 5 | Gate opening at outlet | 0.3 | m |

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The projected length of vane is decided by considering the clearance to the walls. Since the supercritical depth at the downstream of the gate varies from 0.01 m to 0.05m, the depth of vane is taken as 0.05 m with minimum thickness which can bear the force of water and also reduce weight of the assembly. Following parameters of vane from table 2 are used for the simulation in CFD for the determination of vane geometry,

**Table 2: Parameters of vane for CFD**

| | | | |
|---|---|---|---|
| 1 | Projected Length | 0.25 | m |
| 2 | Depth | 0.05 | m |
| 3 | Thickness | 0.0015 | m |
| 4 | Submergence in Water | 0.05 | m |

By using above parameters the simulation was done for different shapes of vanes and maximum force for each condition is found out. The simulation was carried out for the vane geometries from flat vane to curved vane via vanes with different included angles ranging from 0° to 295° facing to inflow as shown in figure 1,

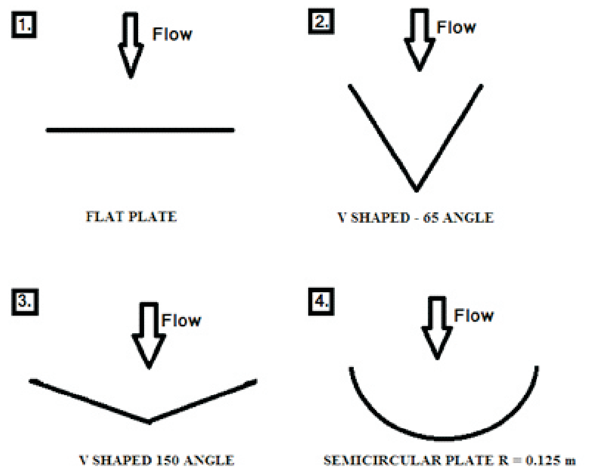


**Figure 1. Vane Geometry**

All the study is carried out with CFD in static vane condition and following results as shown in table 3 are obtained and plotted as shown in figure 2,

**Table 3: Observations of CFD testing**

| Vane Geometry | Included Angle (Facing Flow) (°) | Force on Vane (N) |
|---|---|---|
| V – Shaped (Concave) | 65 | 25.1536 |
| | 100 | 28.8649 |
| | 120 | 30.9567 |
| | 150 | 31.1859 |
| | 155 | 30.4566 |
| | 160 | 30.0234 |
| | 165 | 29.7826 |
| Flat Vane | 180 | 23.6519 |
| V – Shaped (Convex) | 195 | 29.5389 |
| | 200 | 30.1538 |
| | 205 | 30.5986 |
| | 210 | 31.8067 |
| | 240 | 30.8865 |
| | 260 | 28.7654 |
| | 295 | 25.2761 |
| Semicircular Vane | R = 12.5 cm | 40.0957 |
| Curved Vane | R = 6.25 cm | 36.0686 |
| Curved Vane | R = 8 cm | 37.5698 |
| Curved Vane | R = 9 cm | 37.8649 |
| Curved Vane | R = 10 cm | 39.3865 |

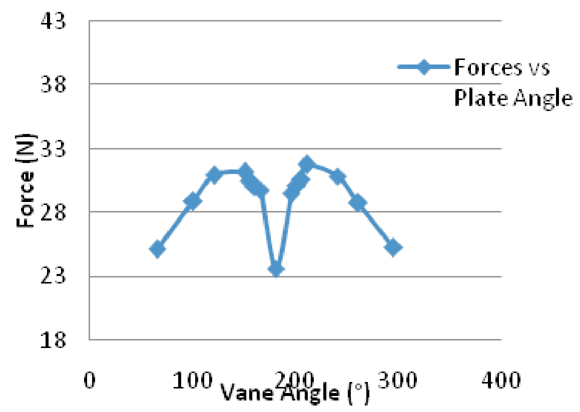


**Figure 2. Included angle vs Force**

From the results obtained from CFD, force acting on vane was maximum for vane with semi-circular geometry. Thus for the model studies, geometry of the vanes is considered to be semi-circular.

**2.4Arrangement of vanes:**

The vanes were arranged on the periphery of the circular wheel with concave face facing water flow. Vanes were fixed such that there should not be interference of successive and preceding vane in the flow of water. These vanes were arranged such that only a single vane comes into the contact of water to avoid cutting of stream by successive vane or backflow by preceding vane. Total 12 numbers of vanes are fixed with included angle between two successive vanes at the centre of wheel as 30° as shown in figure 3. Each vane further tilted at an angle of 5° to avoid interference completely.

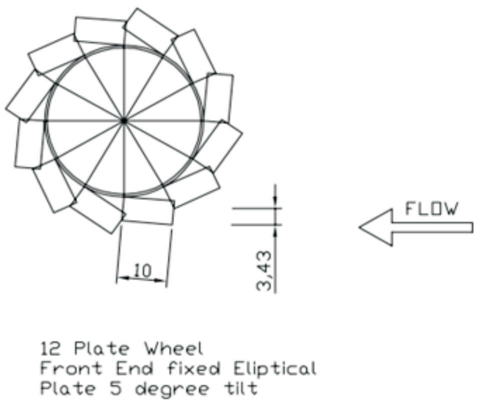


**Figure 3. Arrangement of vanes**

To match the circular wheel surface the profile of vane is changed to curved bottom and top instead of flat surface as shown in figure 4.

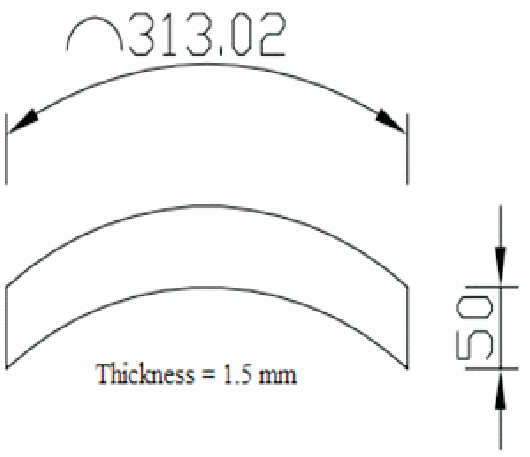


**Figure 4. Profile of vane**

**3. Model setup and testing:**

Based on the CFD results the best output is chosen for the model testing in tilting flume. Physical model is prepared by scaled down to the actual canal data cited by Mr. Mandavia A. B. [5].

**3.1Scaling down the model:**

The prototype has been converted to model by using a suitable scaling factor of 10. Table 4 shows the scaled parameters from prototype to model to facilitate the testing of wheel,

**Table 4: Scaledparameters**

| Sr No | Parameter | Prototype | Model |
|---|---|---|---|
| 1 | Width of channel | 3 m | 0.3 m |
| 2 | Width of gate | 2.8 m | 0.28 m |
| 3 | Velocity | 9.904 m/s – 7.672 m/s | 3.132 m/s – 2.426 m/s |
| 4 | Discharge | 6.324cumec | 0.02 cumec |
| 5 | Head Available | 5 m – 3 m | 0.5 m – 0.3 m |
| 6 | Width of wheel | 2.5 m | 0.25 m |

**3.2Fabrication and experimental arrangement of Model:**

The model was fabricated for the testing in the tilting flume by considering above scaled parameters. Curved vanes were fixed on the periphery of a bicycle wheel with bearing and chain mechanism. Chain and gear arrangements were used to magnify the number of rotations of the wheel. Arrangement of model is as shown in figure 5 and figure 6,

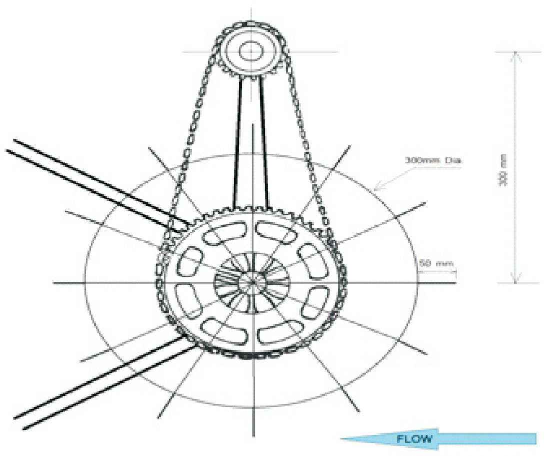


**Figure 5. Wheel and chain arrangements**

The assembly was kept in the channel vertically with vanes submerged in the water with required vane submergence. Shaft of smaller gear was taken out to couple with the alternator for conversion of power.

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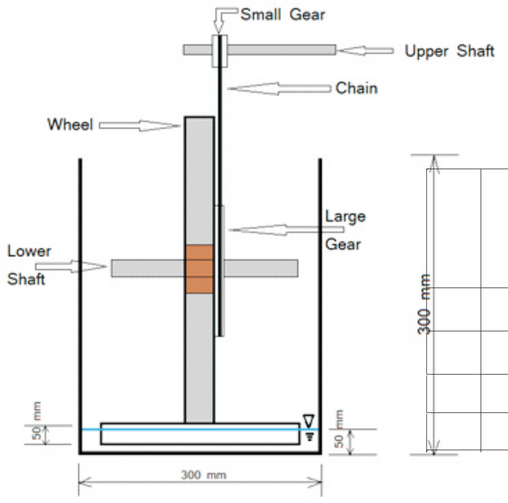


**Figure 6. Experimental setup**

Clearance of 0.015 m is given below the vane from channel bed.

### 3.3Experimental procedure:

Two conditions were considered during the testing of model viz. water depth in the channel and vane submergence. Supercritical flow with Froude number ranging from 4.0 to 6.5 is maintained in the channel in the downstream of the gate. Gate opening was varied such that the water depth varies from 0.02 m to 0.05 m with variation in head from 0.34 m o 0.45 m. This will result in vane submergence from 10% to 70% of vane depth.

By using the above mentioned data velocity of supercritical flow, discharge in contact with the vanes, number of rotations per minute and torque has been measured for each of the condition. Number of rotations of shaft and torque were used to find out the power generation potential of the wheel. Also it is compared with the actual water power potential. It is observed that nearly 45% of water power can be extracted by using this wheel. The results of experimentation are presented in table 5,

**Figure 7. Fabricated Model**

### 4. Analysis and observations

Experimentation and testing of model indicates that the wheel produces maximum rpm and torque of 54.38 and 3.72 N-m respectively for 50% submergence of vane. Above results are obtained with head of 0.36 m and approach velocity of 2.65 m/s.Table 5: Observations of model testing

| Plate submergence (%) | Rpm of Shaft (Nos) | Velocity (m/s) | Discharge (cu.m./s) | Torque (N-m) | Power generated (w) | Water Power (w) |
|---|---|---|---|---|---|---|
| 0.1 | 40.625 | 2.05 | 0.003 | 1.962 | 8.343 | 11.312 |
| 0.3 | 53.125 | 2.05 | 0.008 | 3.335 | 18.546 | 33.936 |
| 0.5 | 54.375 | 2.05 | 0.013 | 3.728 | 21.216 | 56.561 |
| 0.7 | 40.625 | 2.05 | 0.018 | 1.962 | 8.343 | 79.185 |

As shown in figure 7, rpm speed of the wheel increases with increase in vane submergence under the constant head and velocity of flow;rpm increases from 41 to 54 with vane submergence of 10% to 50 % and again reduces with further increase in submergence.

The power generation increases from 8.343 watt to 21.216 watt as vane submergence increases from 10% to 50% and again reduces with further increase in vanesubmergence. The efficiency of the wheel ranges from 40% to 50%.

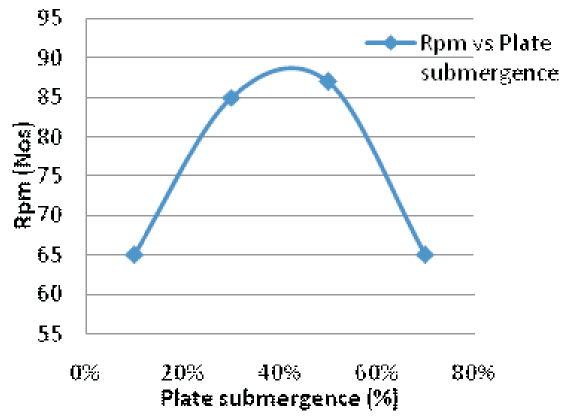


**Figure 8. Rpm Vs VaneSubmergence**

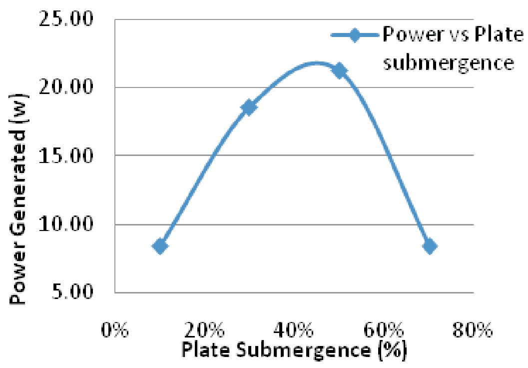


**Figure 9. Power Vs Vane Submergence**

**CONCLUSIONS:**

As per CFD findings, the maximum force was observed to be exerted on semicircular vane.

As vane submergence increases from 10% to 50%, the rpm, torque and power increases proportionally. With further increase in vane submergence, values of above parameters start reducing.

The rpm, torque and power generation is maximum for the vane submergence of 50%. It gives the peak values of 55, 3.728 N-m and 21.21 w respectively.

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