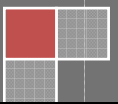
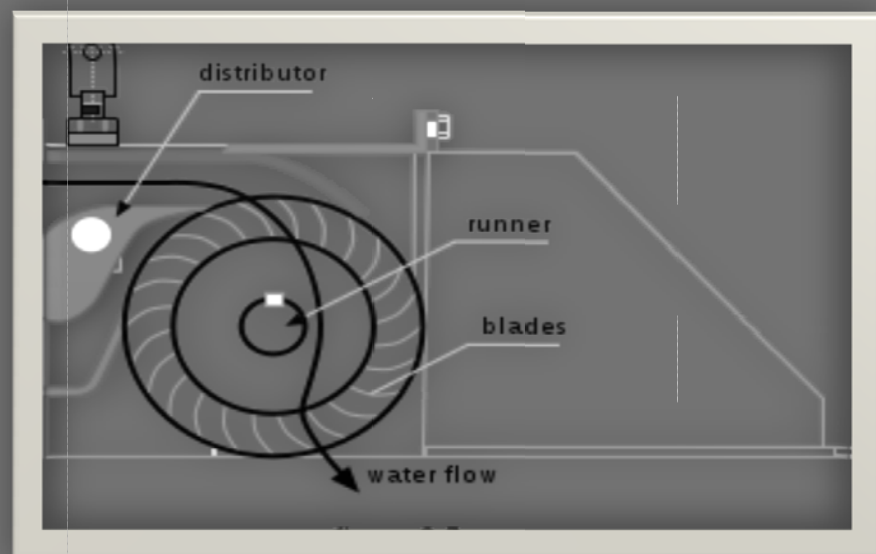
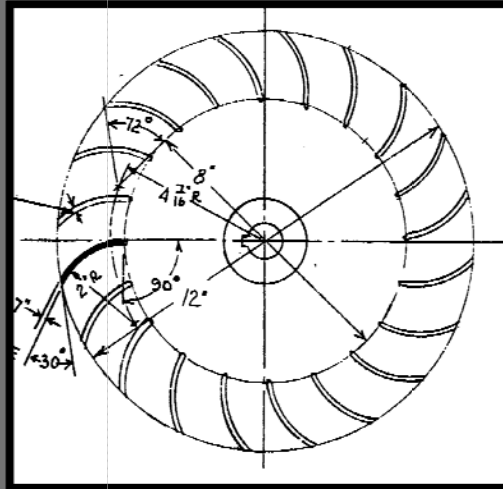


2010

Cross-Flow Water Turbine

A Design Manual

A quick and reliable guide to the designing of a cross-flow water turbine



THE CROSS-FLOW WATER TURBINE

-Also called the Banki-Mitchell-Ossberger Turbine

A Design Manual (Metric System)

The cross-flow water turbine is widely considered by many to be the most efficient and apt type of turbine for applications in micro-hydro and pico-hydro projects.

However, it should also be noted that designing this kind of a turbine is no child's play.

Nevertheless, in this article, I will show you exactly how the designing of the turbine is to take place. With a very basic knowledge of mathematics, it is possible to design and construct an efficient working water turbine.

Before, designing, just get an idea about how much hydraulic power is theoretically available at a particular site.

Use this equation to find power:

$$P = \rho g H \times Q$$

Input g in m/s^2 (it is generally considered to be $9.8m/s^2$), ρ is density of water in kg/m^3 (standard accepted value is $1000kg/m^3$), H is the head in meters and Q is the volume flow rate in m^3/s . the power obtained will be in watts.

A. ASSESS THE SITE AND SITUATION:

The most essential thing to get right is the site. Visit the site and assess it for the head of water that is available. The head is the vertical distance the water will fall before impacting the turbine. Feel free to use any units of your choice, but before putting them in the formula, convert them to meters.

Calculate the flow of the river or stream. It is very essential that you get this very accurately. There are various ways of measuring the flow. Use any method that you find convenient and is compatible with your site. Again, use any units of your choice but ultimately convert them to cubic meter per second.

B. DETERMINING THE LENGTH AND DIAMETER OF TURBINE:

Now the real designing part begins. After you obtain the values of head and flow, use this formula:

$$LD = 2.627 \frac{Q}{\sqrt{H}}$$

You will now obtain the product of L and D as a constant value. Now, give some values to D and find the corresponding values of L . Tabulate these values in a table. Choose any value of L that you feel is convenient to use and does not make the construction too hard or cumbersome. All parameters like blade spacing, jet thickness, maximum efficiency speed and diameter will change accordingly as you change your choice of L . Remember, input values in meters only, or else you will not get correct results. You might be thinking that this is too vague to be accurate or efficient, but don't worry. The result you see above is

an outcome of very tedious and accurate calculations. You can check out the demonstration which I have provided at the end of this manual.

C. N-THE MAXIMUM EFFICIENCY SPEED:

Calculate the value of N using this formula:

$$N = \frac{39.81\sqrt{H}}{D}$$

N obtained here will be in RPM (Revolutions per Minute). Remember, the turbine will be most efficient when running at this speed. However, The Cross-Flow turbine can work very efficiently even under a good deal of variation in head and flow.

D. DETERMING THE BLADE SPACING:

Blade spacing is the distance between the tips of two adjacent blades on the outer periphery. This quantity is usually denoted by t. Evaluate t by

$$t = \frac{kD}{\sin \beta}$$

Here k is a constant whose value is 0.087 and β is 30° , so $\sin \beta$ will be 0.5. Thus simplifying, we obtain,

$$t = 0.174D$$

When you get down to sketching this after all these calculations, you will find that the number of blades invariably is 18. This is actually the optimum number of blades although higher as well as lower numbers of blades have been used. However, my advice to you would be to just follow these steps and everything will take care of itself. The calculations would otherwise become quite tedious.

E. AREA AND THICKNESS OF JET:

The area of jet can easily be determined. This also enables us to calculate the optimum thickness of the jet, which is the same as nozzle width s. Use this formula,

$$s = 0.22 \frac{Q}{L\sqrt{H}}$$

F. RADIAL RIM WIDTH:

The radial rim width is the difference between the outer radius and inner radius. This zone starts from the outer radius and ends at the inner one. This space contains the blades. This is denoted by a.

$$a = 0.17D$$

The outer radius is denoted by r_1 , which is equal to $D/2$. Also, the inner radius r_2 is given by

$$r_2 = 0.66r_1 = 0.33D$$

G. RADIUS OF BLADE CURVATURES:

All the blades are actually arcs of a circle. You need not worry yourself with how the radius is obtained and the theory behind it; I have done that for you. To determine the radius of curvature of the blades ρ ,

$$\rho = 0.163D$$

H. CONSTRUCT:

Now is the part that requires some concentration- how to construct, on paper, the structure of the water turbine. Take a graph paper. Using a graph paper for construction has many advantages. It is much easier to understand the scale of the project on graph paper and much less chances of making any error.

- I. Select a point O as the center of the circle. Using a compass, draw a circle about this point with a diameter D. Choose any point on the circumference and name it A.
- II. Draw an inner circle within the outer circle about the same point O with a radius r_2 .
- III. Draw a radius extending from O to A. From A, draw a tangent AB to the circle. Using a compass would be better than using a set square or protractor.
- IV. At A, construct a 30° angle BAE.
- V. Now construct a perpendicular AD on the line AE at A.
- VI. Calculate the value of the radius of curvature ρ from the formula in section G. After you have obtained this value, measure out this distance on the line AD and cut an arc at C. AC so formed is the radius of curvature and C is the center of the circle of which the blade is an arc.
- VII. Now, with the center at C and radius ρ , draw an arc starting from A and meeting the inner circle at S. That's it! The arc AS so formed is your first blade.
- VIII. Now with your center at O and radius OC, draw another circle. You will notice that this circle is slightly greater than the inner circle.
- IX. Calculate the value of t, the blade spacing, from the formula in section D. Measure out this value on the compass. Taking this value, start from A and cut an arc on the outer circumference (marked as 1). Proceeding in the same manner, cut out arcs along the whole length of the circumference- 2, 3, 4, 5.....
- X. Taking ρ as radius, Position the compass on these arcs and intersect the intermediate circle at points a, b, c, d, e..... . All these intersection points will be the centers of the circles whose arcs will give us the blades.
- XI. Now position your compass on these intersections and taking the radius ρ , draw arcs from the outer circle to the inner circle (the inner-most circle; the circle whose radius is r_2). The arcs so formed are thickened in the illustration.
- XII. Your turbine design is now complete.

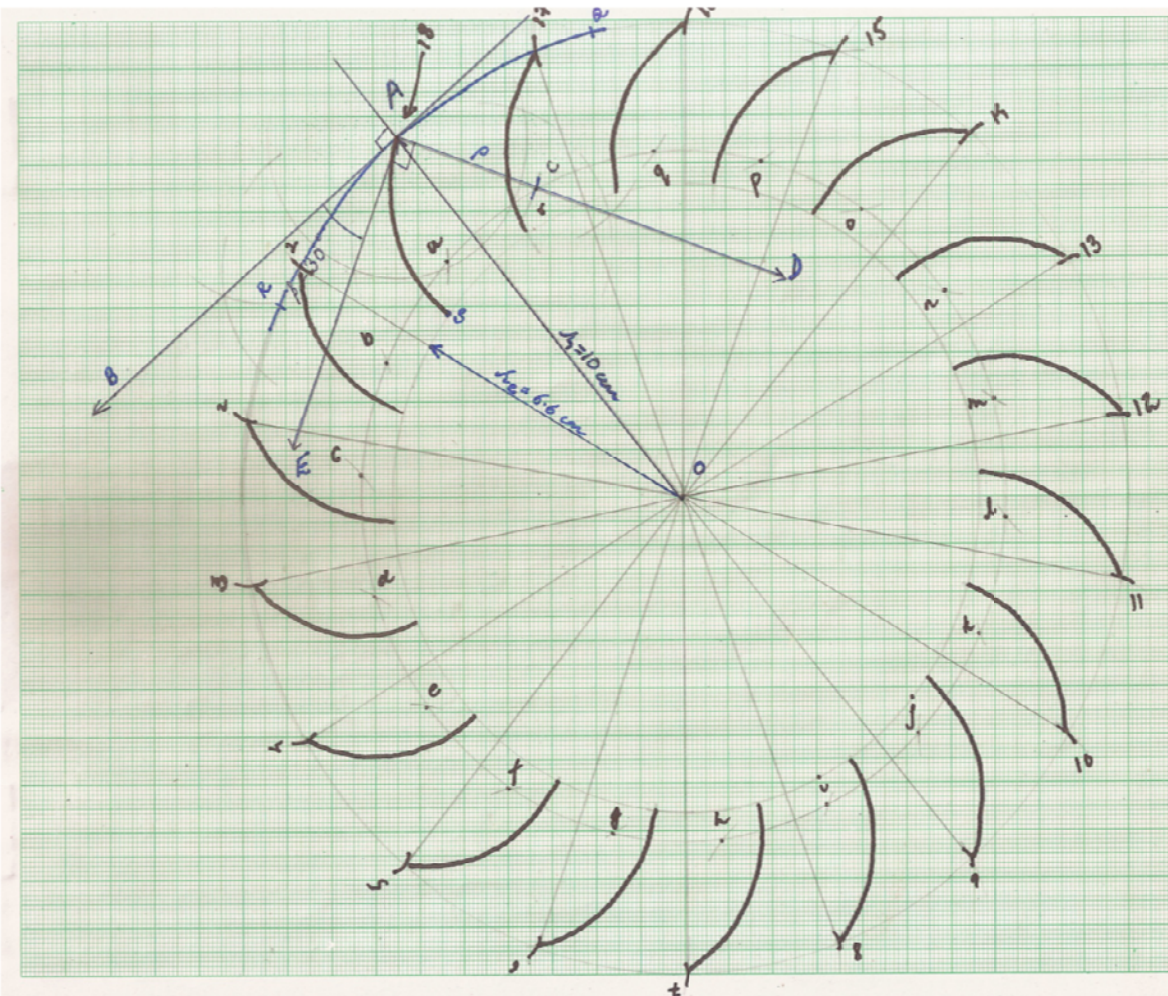
SOME OTHER DESIGN PARAMETERS:

Some design parameters have been derived after intense theoretical study and are now the standard accepted values. The most notable among these is the angle of attack of the nozzle α . First of all, a point on the turbine is selected where the jet is to be admitted. A tangent to this point is drawn and the jet is angled at an angle of 16° . α is universally accepted as 16 degrees.

$$\alpha = 16^\circ$$

On the next page you will find a sample design. This will give you an idea on how to proceed with the drawing.

The diameter is taken to be 20cm. The corresponding parameters are all calculated and tabulated for your convenience.



PARAMETER	VALUE (in meters)*	VALUE (In centimeters)*
Diameter - D	0.20	20
Blade Spacing - t	0.052	5.2
Rim Width - a	0.034	3.4
Inner Radius r_2	0.066	6.6
Radius of Curvature -	0.033	3.3

ILLUSTRATIVE EXAMPLE:

Let us now use all these equations and derive all the dimensions using the given data. This will help us better understand the parameters required and how they are to be found out.

Take this case: - we are given a site with these values-

$$Q = 0.1 \text{ m}^3/\text{s}$$

$$H = 3.5 \text{ m}$$

First of all, we calculate the theoretical hydraulic power available:

$$P = 1000 \times 9.8 \times 3.5 \times 0.1$$

$$= 3430 \text{ W}$$

$$= 3.43 \text{ kW}$$

Using the formula in section B, we find the product of D and L.

$$LD = 2.627 \times \frac{0.1}{\sqrt{3.5}}$$

$$LD = 0.14$$

We give D some values and tabulate the corresponding values of L. Input values in meters.

D (meters)	L (meters)
0.50	0.28
0.45	0.31
0.40	0.35
0.35	0.40
0.30	0.47
0.25	0.56

We select D=0.30 meters and L=0.47 meters.

$$D = 0.30 \text{ m}$$

$$L = 0.47 \text{ m}$$

Now we find the maximum efficiency RPM.

$$N = \frac{39.81\sqrt{3.5}}{0.30}$$

$$N = 248.25 \text{ RPM}$$

$$\therefore N \approx 249 \text{ RPM}$$

The blade spacing t is

$$t = 0.174 \times 0.30$$

$$t = 0.052 \text{ m}$$

$$\therefore t = 5.2 \text{ cm}$$

The nozzle width s is

$$s = 0.22 \frac{0.1}{0.47\sqrt{3.5}}$$

$$s = 0.025 \text{ m}$$

$$\therefore s = 2.5 \text{ cm}$$

The radial rim width is

$$a = 0.17 \times 0.30$$

$$a = 0.051 \text{ m}$$

$$\therefore a = 5.1 \text{ cm}$$

The inner radius is therefore

$$r_2 = 0.33 \times 0.30$$

$$r_2 = 0.099 \text{ m}$$

$$\therefore r_2 = 9.9 \text{ cm}$$

$$r_1 = 0.15 \text{ m} = 15 \text{ cm}$$

The radius of curvature ρ is

$$\rho = 0.163 \times 0.30$$

$$\rho = 0.049 \text{ m}$$

$$\therefore \rho = 4.9 \text{ cm}$$

Before beginning your drawings, just tabulate these values and keep them at hand to avoid any sort of confusion.

PARAMETER	VALUE (in meters)*	VALUE (in centimeters)*
Length - L	0.47	47
Diameter - D	0.30	30
RPM - N	249 RPM	249 RPM
Blade Spacing - t	0.052	5.2
Nozzle Width - s	0.025	2.5
Rim Width - a	0.051	5.1
Inner Radius r_2	0.099	9.9
Radius of Curvature - ρ	0.049	4.9

*All units as shown in the leading column header unless clearly stated otherwise.

Feel free to contact me if you have any doubts. I would be happy to clear them.
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