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Highly Efficient Cross flow Turbine Runner Design for Upgrading Traditional Water Mill in to Micro Hydro Power Plant

(A case Study for Kersa-Minko Village)

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***Abstract*—Cross flow turbines, which are suitable in upgrading traditional water mills in to hydro power generating systems in Ethiopia and in general in developing nations creates high interest, due to their simplicity for manufacturing in simple local metal workshops, suitable operating condition for large load variation conditions, the ease of operation and maintenance by low skill remote rural farmers in areas which are detached from the main grid line and apart from most hydraulic turbines their suitability for low head and flow rate conditions . Therefore, in this paper the design of highly efficient cross flow turbine runner for upgrading traditional water mill in to micro hydro power plant and water mill in Kersa-Minko village is conducted. The design includes calculations that determine runner diameter, runner length, runner speed, turbine power, water jet thickness, blade spacing, number of blades, radius of blade curvature, attack angle and the blade inlet and exit angles.**

Keywords—Cross flow; turbine; runner; flow rate, head, blades.

I. INTRODUCTION

Ethiopia with a population of 92 million in 2012, with 85% of the people in the nation are living in remote rural villages with their income mainly from agriculture.[2] the settlers in this villages live in a scattered manner for the sake of managing their land. Ethiopian people consider electric power as a luxury enjoyed by a few people in urban areas, which results in migration to the urban areas and abroad to different Arab and western nations for the sake of better life, this days such problems are creating savior problems for the government and people of the nation. therefore creating awareness through technological developments and providing ways for better living standards is the main mechanism in minimizing the problems and developing the nation.[6,7]

In Ethiopia in 2012 about 2100Mw electricity generated mainly from hydropower and the GTP-1 plan states the country should have 8000 Mw at the end of the five year GTP-1 in 2015. Apart from the large hydro power plants available in the country the highland topography of the country which is suitable for small, micro and Pico hidro power plants, for having sufficient head or elevation for generating power from water by using the large number of annual flowing rivers which are available in almost all rural villages of the country, despite the fact that transmission of power to this rural remote villages from the main grid with difficult topography creates an interest to develop small, Pico, micro and ultra low head hydro power projects which can be managed in decentralized manner with their estimated potential of 1500- 3000Mw[6,7]

In addition, the indigenous knowledge of grain milling using the power of water from small annual flowing rivers, creates interest to undergo further technological development by higher institutions like Jimma University and different governmental and nongovernmental organizations like Alphasol Modular Energy, Agricultural Mechanization Research Institute, GIZ-ECO etc. by using the power from in Ethiopia remote rural villages.[7]

Only in Jimma Zone which is situated in the south western part of the nation there are more than 60 traditional water mills which can be easily upgraded in to micro hydro power generating system by performing minor adjustment in the existing head race canal and diversion wear, and by installing locally made efficient electro mechanical system, in this respect the efficiency and suitability for technology transfer of the turbine plays an important role in disseminating the technology to the rest remote villagers of the nation.

This days, the cross-flow hydraulic turbine is gaining popularity in low head and small water flow rate establishments, due to its simple structure and ease of manufacturing in local metal work shops. the standard and latest cross flow turbine known T-15 is manufactured by lather process do have efficiency of conversion from kinetic energy of water in to mechanical energy accounts 80% which is the best turbine, but this manufacturing process is not economical in developing nations. In Ethiopia the maximum efficiency gained from cross flow turbine is about 70% which is highly recommended in the context of the nation.

The cross-flow turbine is composed of two major parts, the runner and the nozzle . the runner was a circular rotor with two side walls to which the blades are fixed along the periphery of the turbine. The cross-section of the blades was circular with specific radius of curvature. The nozzle directs the water flow into the runner at a certain attack angle and a single water jet penetrates the turbine blade twice, this is a similar process like that of two turbines work for an output, such feature provides larger efficiency.

The traditional water mill is situated on Kersa-Minko River, Toli Kersu village, Kersa Province, Jimma Zone of the Oromia Regional State of Ethiopia at about 321-km south west of the capital, Addis Ababa on the route Addis Ababa- Jimma. The approximate geographical co-ordinates of the area is 70 44.44’ N, 370 00.14’ E. at an altitude of 1740 to 2660 meters above sea level.

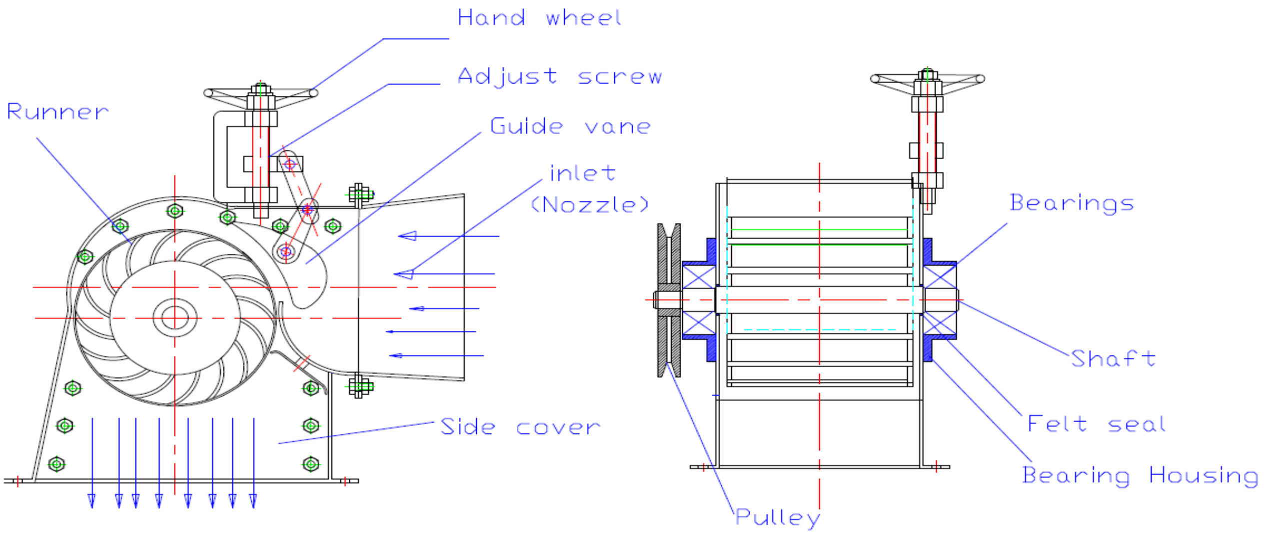

Fig. 1. Cross Flow Turbine Runner with Housing

In this work the design steps of cross flow runner for Kersa-Minko river flow considering the dry season water flow, and diversion water flow less than 30% of the main river flow in order not to affect the main stream environmental conditions.

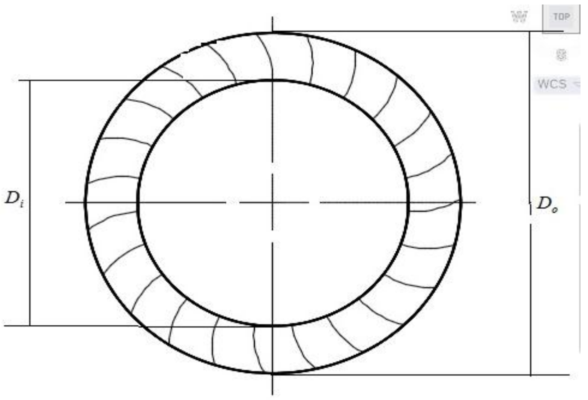

Fig. 2. Cross flow turbine runner

The design includes calculations that determine runner diameter, runner length, runner speed, turbine power, water jet thickness, blade spacing, number of blades, radius of blade curvature, attack angle and the blade and exit angles. Further recommendations for maximum output while installing the plant is also provided.

II.DATA COLLECTION AND ANALYSIS

The most important data in the design of hydro power plant is the head and the flow rate,

Head

$$H_{net} = H_{gross} - H_{losses} \tag{1}$$

Where:

(H_{gross}): Gross Head(m), the elevation difference from the head race canal to the turbine exit.

The gross head is the elevation difference from the head race canal to the turbine exit for kersa-minko is measured using sight surface leveling and found to be (11.8meter)

(H_{losses}): Head loss(m), This includes the different losses of water flowing from the forbay tank until it penetrates the turbine runner, which includes, trash rack loss, entrance loss, fanning friction loss in the penstock, joint and bending losses, valve losses, and summing up all this results, or considering 6-10% of the gross head. (1.3m)

Therefore, for kersa-minko flow the net head considered is H_{net}=10.5m.

Flow Rate

Kersa-Minko river water flow which is found in the Giba basin have annual flow duration, shown in the figure. In this work the flow less than 30% of the main stream in kersa-minko river is considered in the dry season for the sake of environmental effects on the main stream flow. Therefore,
the flow in the head race canal considered is

$$\left(Q = 0.2\, m^3/Sec.\right)$$

Efficiency

the maximum efficiency of cross flow turbine mainly depends on the angle α(angle of attack) between the particle velocity and the tangent direction at the impeller inlet, but according to different researches the maximum efficiency is obtained when the angle of attack $(\alpha = 22^0)$, the blade roughness coefficient (ψ =0.98), and Nozzle roughness coefficient (C=0.98)

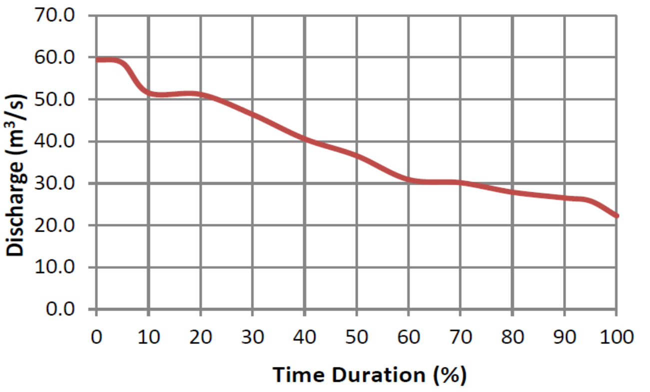

Fig. 3. Flow duration curve at Gilgel Gibe river flow

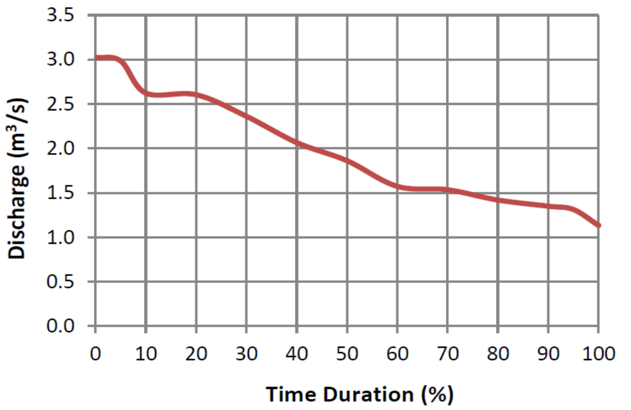

Fig. 4. Flow duration curve at kersa-Minko river flow

$$\eta = \frac{1}{2} \times C^2 \times (1+\psi) \times \cos^2(\alpha) \text{ [3]} \qquad (2)$$

the maximum efficiency becomes η =81%, but due to manufacturing problems, the efficiency considered in this work is 65%.

Turbine power out put

$$P_t = \eta \times \rho \times g \times H_{net} \times Q = 13.4Kwt \qquad (3)$$

Speed of the Turbine (N_T)

the specific speed correlation with the net head is given by

$$N_s = \frac{513.25}{H_{net}^{0.505}} = 156.5 \qquad (4)$$

$$N_T = \frac{513.25 \times H_{net}^{5/4}}{\sqrt{P_t}} = 808 \text{ rpm} \qquad (5)$$

Turbine runner outer diameter (D_o)

$$D_o = 40 \times \sqrt{H_{net}} / N_T = 0.1604\text{m} \qquad (6)$$

Jet Thickness (t_e)

The thickness of jet entrance, measured at right angles to the tangential velocity of runner is given as

$$t_e = K \times D_o \qquad (7)$$

Where K=0.087

t_e =0.014m

Blade spacing (t_b)

The tangential blade spacing,

$$\tan(\beta_1) = 2 \times \tan(\alpha) \qquad (8)$$

where, β_1: Blade inlet angle $(\beta_1 = 39^0)$

The tangential spacing t_b is given as,

$$t_b = \frac{t_e}{\sin(\beta_1)} = 0.02225\text{m} \qquad (9)$$

Radial rim width (a):

It is the difference between the outer radius (r_o) and inner radius (r_i) of the turbine runner, and it is also equal to the blade spacing and can be given as:

$$a = \frac{K}{\sin(\beta_1)} \times D_o = 0.02225\text{m} \qquad (10)$$

Number runner blade (n)

The number of the runner blades can be determined as,

$$n = \pi \times \frac{D_o}{t_b} = 22.65 \cong 23 \text{ blades} \qquad (11)$$

Water jet thickness (t_j), and runner length (L)

It is also defined as nozzle width and can be calculated as,

$$L = \frac{Q \times N_T}{50 H_{net}} = 0.308\text{m} \qquad (12)$$

and the water jet thickness is given by,

$$t_j = 11.7 \times \sqrt{H_{net}} / N_T = 0.047\text{m} \qquad (13)$$

Distance between water jet and the center of runner shaft (y_1)

the radius of the runner is the sum of , the water jet thickness, the radial rim width, the distance between water jet and the center of runner shaft, and the distance between water jet and the inner periphery of runner.

$$r_o = y_1 + t_j + y_2 + a \qquad (14)$$

And,

$$y_1 = 0.116 \times D_o = 0.0186\text{m}$$

Distance between water jet and the inner periphery of runner (y_2)

$$y_2 = 0.05 \times D_o = 0.00802\text{m}$$

The exit blade angle, (β_2) considered is 90° for perfect radial flow, and is equal to (β_1) for maximum efficiency,

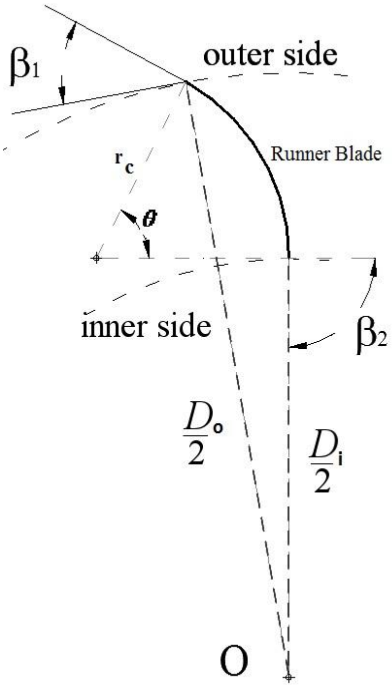

Fig. 5. Blade Geometry

The radius of blade (r_c) is calculated as,

$$r_c = \frac{D_o}{4}\left[1-\left(\frac{D_i}{D_o}\right)^2\right]\cos(\beta_1)^{-1}=0.072\text{m [4]} \qquad (15)$$

The central angle (θ) of the blade angle which depends basically on the inlet blade angle, is given by,

$$\theta = 2\tan^{-1}\left(\frac{1}{\tan(\beta_1)}\right) = 31^0 \qquad (16)$$

III. CONCLUSION

The complete design of cross flow turbine runner parts considering the maximum efficiency depending on the local manufacturing facilities is performed. The complete runner components, including runner outer and inner diameter, runner length, runner speed, turbine power, water jet thickness, blade spacing, number of blades, radius of blade curvature, attack angle and the blade inlet and exit angles for the case of Kersa- Monqo river is calculated. the design of the other components like penstock, forbay etc., which is not incorporated in this work also determines the safe and optimum operating conditions of the turbine runner and in general, the hydro power plant.

IV. NOMINICLATURE

α	Angle of attack
ψ	Blade Roughness Coefficient
C	Nozzle Roughness Coefficient
η	Efficiency of Turbine
ρ	Density of Water
g	Acceleration due to gravity
N_T	Runner Speed
N_s	Specific Speed
D_o	Outer diameter of Runner
D_i	Inner diameter of Runner
t_e	Water Jet Entrance Thickness
t_b	Blade Spacing
t_j	Water Jet Thickness
B_1	Blade Inlet Angle
B_2	Blade Exit Angle
a	Radial Rim Width
n	Number of Blades
L	Length of Runner

IV. ACKNOWLEDGMENT

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