Design and Optimization of Pelton Wheel Turbine for Tube-Well

Faiz Ahmed Meeran[1], Muhammad Arslan[2], Ali Raza Mansha[3] and Aamir Sajjad[4]

[1]Karachi Institute of Power Engineering
[2]Mechanical Engineering Department, UET, Lahore
[3]Mechanical Engineering Department University of Sargodha
[4]Mechanical Engineering Department, RCET Gujranwala

[1]engineerfaizi8@gmail.com, [2]arslan.unique@gmail.com, [3]engralirazamansha76@gmail.com, [4]aamir.sajjad481@gmail.com

Abstract– **In this work a Pelton wheel was designed and optimized which can be installed on tube well and can work as portable power generation system. This work is done by keeping in mind the current energy scenario of Pakistan. After designing, optimization is made by changing different parameters i.e., number of buckets, number of jets, diameter of jet, angle of deflection and jet ratio. And different characteristics curves are plotted and compared to select parameters giving maximum efficiency. By installing this turbine on ordinary (14 cm outlet pipe diameter) tube-well, the approximated output power is 2.8 KW. This work is done because of accountable potential at tube wells in Pakistan. Keeping in mind the compactness, bulkiness, cost and portability of turbine the fly-wheel was accommodated at the circumference of the wheel.**

Keywords– **Pelton Wheel Design Optimization, Portable Power Plant and Tube-well**

I. INTRODUCTION

In world's energy generation facilities hydroelectric generation plays an important role. As in 2010 it was estimated that hydroelectric generation is about 16% of global electricity generation [1]. In Punjab, Pakistan there were approximately more than 9lac tube wells in 2006 with annual growth 6.12% [2], by installing our proposed turbine we can obtain 2.8 KW of power per turbine and the total potential is about 2520 MW. These types of facilities having generation capacity less than 5KW usually called as Pico-hydropower plants and these are also cost effective [3]. As in Pelton wheel turbine more than 90% of water power can be converted into mechanical power [4].

Hence, in this work 81.5% efficiency is obtained by changing different parameters again and again. Finally some recommendations are made in order to get maximum performance. As tube well does not work 24 hour a day thus we require some storage facilities so that we may get power even when the tube well is in off condition. The energy obtained from the turbine can be used to obtain larger volume flow rate of water by installing a small pump which in turn increases the efficiency of our system and decreasing the irrigation cost. For this the output shaft of the turbine acts as prime mover for the smaller pump. Secondly this system may be utilized to generate the electricity for running fans and lights. Here is a graph from which we can estimate the potential of energy sources requires by the tube-wells in Pakistan. This work will help to obtain reasonable amount of energy from ordinary tube well. While designing and optimizing the turbine it was kept in mind to use standard accessories so that we may reduce the cost and to facilitate the fabrication.
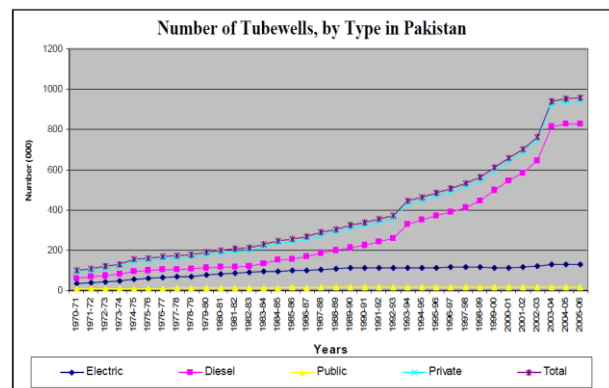

Fig. 1: (Number of tubewells in Pakistan Vs years) [2]

Table 1: (Annual Growth of tubewells (%)) [2]

Annual Growth Rate of Tubewells	Diesel	Public	Private	Total
Annual Growth (%)	2.96	7.30	6.31	6.12

II. EXPLANATION

Following are the most important parameters used while designing. V_1, V_2 are the absolute velocities of the jet at the inlet and outlet respectively. The u_1, u_2 are the peripheral velocities of the vane at the inlet and outlet respectively. Vr_1, Vr_2 are the relative velocities at the inlet and outlet respectively. V_{f1}, V_{f2} are the Velocities of the flow at the inlet

and outlet respectively. Vw_1, Vw_2 are the velocities of the whirl as the inlet and the outlet respectively. θ, φ are the tip angle at the inlet and the outlet respectively. α, β are the angles which the absolute velocities makes at the inlet and outlet.
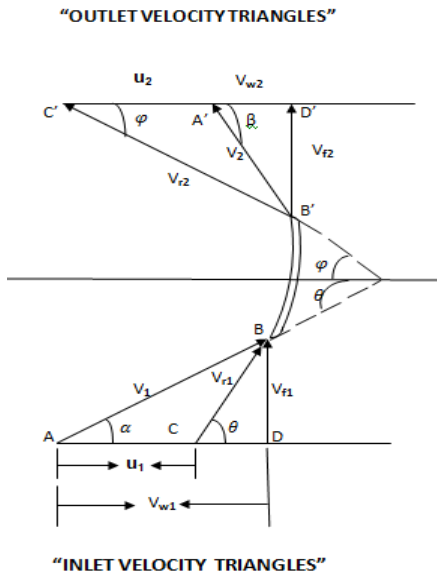

Fig. 2: Bucket inlet and outlet velocity triangles

III. OPTIMIZATION USING COMPARISON CURVES METHOD

These calculation were made for the tube well of 14 cm diameter of outlet pipe and then four jets are installed each of 2.5cm diameter. Means 4cm of diameter not used hence this will increase the velocity head at the jets.

Design procedure from [5] is adopted and Microsoft Excel program is written for optimization purpose.

A. Head vs Power Developed

As we are much more interested in power developed. So, if we have a look at the graph we come to know that the head is directly proportional to the power developed.
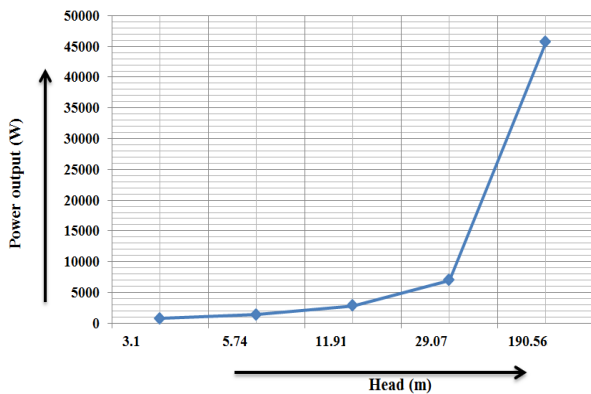

Fig. 3: Head vs power developed

As head increases power output increases but in this case increase in head is due to decrease in jet diameter and most suitable value for head is 12m to get maximum power efficiently.

B. Jet Diameter vs Head

When the jet diameter decreases the velocity head increases. And it is required to get maximum velocity head to obtain maximum output power. So it is proposed that instead of one, four nozzles of 0.025 m diameter each are suitable to get maximum head.

If we decrease the diameter further the head increases very rapidly but this makes the jet diameter too small and affects the life of pump.
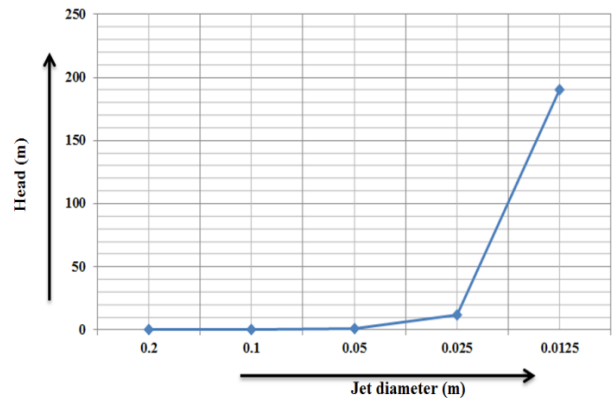

Fig. 4: Jet diameter vs head

C. Jet Diameter vs Power Produced

By decreasing the jet diameter the power produced increase. Because the head increases as according to the previous graph. We can conclude from this graph that the suitable value of the diameter is again 0.025m keeping in view the power output.

Now from above three graphs we are able to finalize the jet diameter and it must be 0.025m to get maximum power with maximum efficiency.
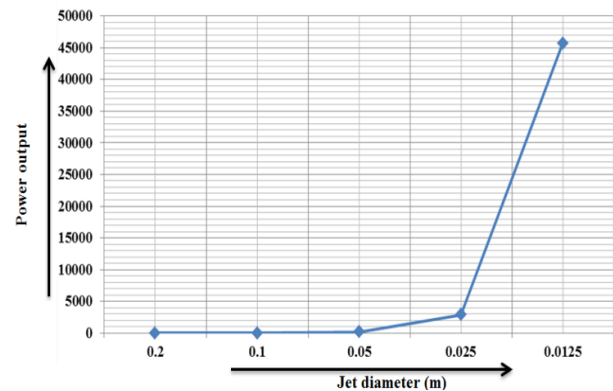

Fig. 5: Jet diameter Vs power output

D. Number of Jets vs Power

As for as number of jets are concerned it should be as more as possible because the increase in number of jets increases flow rate and velocity gained by the wheel increases. But technically speaking this happens to a certain limit. After that limit increase in number of jets decrease the power produced. It is because the total area of jets becomes large and according to the equation of continuity velocity of water at the outlet of the jet decreases due to increase in the total area of the jets. Hence the maximum number of jets proposed for this vertical shaft Pelton wheel turbine is 4.
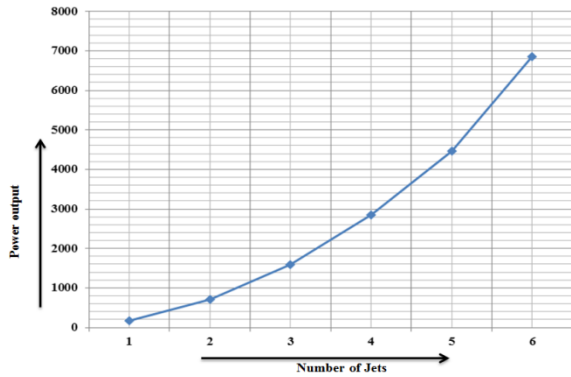

Fig. 6: Number of jets vs power

E. Jet Ratio (M) vs RPM

When we increase the jet ratio i.e., the ratio of diameter of wheel to the jet diameter, the RPM of the turbine rotor decreases due to increase in the diameter of the wheel. The very small value of jet ratio increases the RPM but again it is not practically possible to decrease the jet ratio from a certain value. If we do so then the torque which plays a vital role in power generation decreases also. After plotting different curves it is decided take this ratio to 13 to get the maximum efficiency.
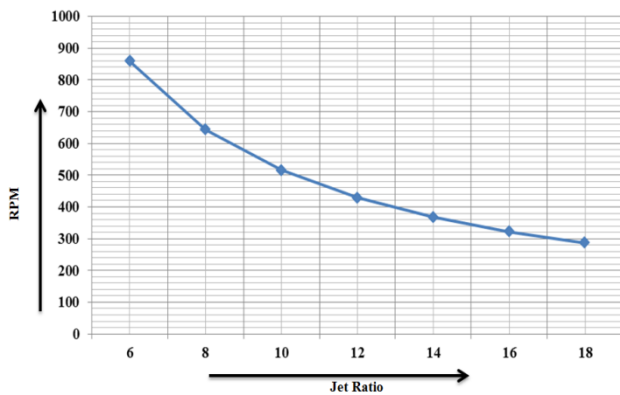

Fig. 7: Jet Ratio (M) Vs RPM

F. Angle of Deflection vs Output Power

As the angle of deflection increases the power developed increases. But power developed increase up to some point after that it begins to decrease. It is because if we increase the angle of deflection more and more than the water after leaving the bucket will strike at the back the of next incoming bucket. This strike will make the wheel to rotate in opposite direction which in turn will reduce the power.
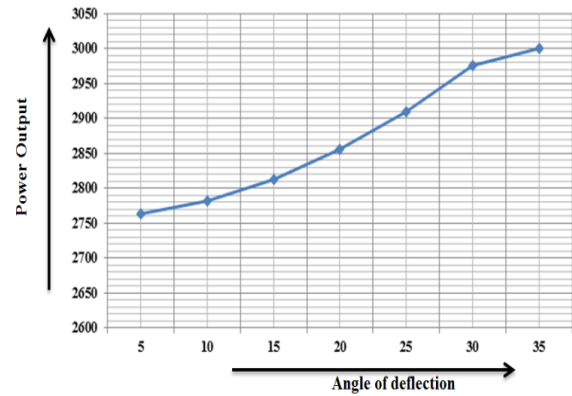

Fig. 8: Angle of Deflection vs Output Power

G. Number of Buckets

Number of buckets has direct relation with power. But too many buckets make the wheel bulky and deceases the efficiency to a reasonable extent. Suitable Number of buckets were determined from table. In this work as selected angle of deflection is 20°. So 24 buckets are selected. Roughly the ratio between wheel diameter to the nozzle diameter which is called jet ratio of 10 is selected [5].

Table 2: Jet ratio and number of buckets [5]

Jet ratio	6	8	10	15	20	25
No. of buckets	17 to 21	18 to 22	19 to 24	22 to 27	24 to 30	26 To 33

IV. MATERIALS SELECTION

The selected material for the runner of the turbine was manufactured in ASTM CA-6NM soft martensitic cast stainless steel (G-X4 Cr Ni 13-4, according to the German DIN designation). Quenched and tempered CA-6NM steel because of high toughness and due to excellent resistance against cavitation erosion is widely used for runner castings for turbomachinery [6] - [9].

V. EFFECT OF JET MISALIGNMENT

Jet alignment is very important because of radial misalignment of jet decrease the efficiency from 15 to 20 percent [10]. So it is proposed to place the jets in such a way

that jet strikes in the middle of the bucket and after striking it converts into to equal streams of water.

VI. ANALYSIS OF TURBINE

The resultant force that a bucket is facing can be calculated by [5]:

$$RESULTANT\ FORCE = \rho Q[V_{w1} - V_{w2}]$$

The bucket have maximum force concentration at the place where jet strikes and this trend decreases while going towards the bucket.

By using this formula is also possible to conduct CFD (computational fluid dynamic) analysis on the turbine to make it more efficient. Stress strain analysis can also be conducted to estimate the life of the turbine.

VII. RESULTS/CONCLUSIONS

In future, putting these portable Pelton wheel turbines at tube-wells will increase the tube-well efficiency. The electricity produced by these turbines can be utilized in running a small pump with the tube-well that will increase the total flow rate. Here are the details of turbine specifications, bucket dimensions and output power for the current designed and optimized portable Pelton wheel turbine for a given tube-well of 14cm outlet pipe diameter.

A. Turbine Specifications

By compiling these results the following specifications for turbine are recommended.

Vertical axis Pelton wheel turbine	
Number of jets	4
Jet diameter	2.5cm
Jet ratio	13
Number of buckets	24
Angle of deflection	20°

B. Bucket Dimensions

Axial width B	8 cm
Radial length L	6 cm
Depth T	2.2 cm

C. Power Output

Power output	2.8 KW

REFERENCES

[1]. International Energy Agency (IEA). Key world energy statistics; 2012.
[2]. http://s3.amazonaws.com/zanran_storage/www.fao.org/ContentPages/93784319.pdf (21-01-2015)
[3]. Sopian K, Razak J. Pico hydro: clean power from small streams. Lalaguna, Spain. In: WSEAS renew energy sources; July 1-3, 2009. p. 414e9.
[4]. Boyle G. Renewable energy—power for a sustainable future. NewYork: Oxford University Press Inc.; 1996.
[5]. D.S. Kumar (Fluid Mechanics And Fluid Power Engineering).
[6]. Iwabuchi Y. Temper embrittlement of type l3Cr–4Ni cast steel. Trans Iron Steel InstJpn 1987; 27(3):211–7.
[7]. Tokuda A, Kumada Y, Nakagawa K. Development and results of a trail production of 13% Cr base cast stainless steel propeller for ships. JSW Tech Rev1970; 27:3142–52.
[8]. Iwabuchi Y, Sawada S. Metallurgical characteristics of a large hydraulic runner casting of type 13Cr–Ni stainless steel. Stainless steel casting, ASTM STP 756; 1982. p. 332–54.
[9]. Larson JA, Fisher R. The effect of heat treatment and melt practice on the impact properties of CA-6NM steel. AFS Trans 1979; 63:113–26.
[10]. Bryan R. Cobb, Kendra V. Sharp (2012) Impulse (Turgo and Pelton) turbine performance characteristics and their impact on pico-hydro installations Renewable Energy.