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DESIGN, CONSTRUCTION AND TESTING OF A PROTOTYPE HYDRO TURBINE

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ABSTRACT

The world is gradually falling back to reliable, efficient and economical means of power generation that is environmentally friendly and can also be sustained on the long run. This project covers the design, construction and testing of a prototype Impulse Hydro turbine, which is a small scale machine that offers an insight to the potential and benefit of utilizing hydro energy in power generation as compared to other sources. This work covers the preliminary design considerations using established engineering calculations, the construction part which covers the manufacturing of several parts (such as the turbine buckets and wheel) by method of casting, machining and finishing, and also fabrication processes for other mechanical parts (Frame, casing, generator/alternator support etc.) like cutting, drilling, rolling, arc welding, grinding, bolting and the incorporation of the parts (both mechanical and electrical). Finally the testing of the design and its power generation are potential in relation to the intended purpose. The turbine works by receiving high pressure jet at a head of about 20m through a nozzle positioned at an angle of 135^0 to the buckets arranged in an equidistant circular array, and the force of the jet propels the wheel which in turn rotates the shaft at a speed of about 210-750RPM generating an electric voltage of about 23.0V when the motion of the shaft turns the generator attached in line with it.

Keywords: Power generation, Prototype impulse Turbine, Renewable Energy Sources, Hydro-electricity, Computational Fluid Dynamics (CFD).Pelton wheel Turbine

INTRODUCTION

Turbines are a device that utilizes renewable energy sources (RES) to generate significant amount of energy. It has been estimated that Turbines are capable of converting over 90% of waters' kinetic energy into mechanical energy .The generation of electricity and energy production using hydropower has gained significant attention recently all over the world especially with the use of pumped storage technology which supports large RES penetration into electric grids thereby raising the capacity factor of existing hydropower installations.The main classical hydraulic turbine types, after their invention in the last centuries, (Francis, 1848; Pelton, 1870; Kaplan, 1913; Turgo, 1919; etc.), are still widely used today and will operate for many more years, since they can cover all possible combinations of hydro power site conditions (head, flow rate, and power variation pattern). The traditional design of these turbines was based on the accumulated experience of the manufacturers and engineers, and from time to time has adopted some improvements, by applying the costly trial-and-error method, and by exploiting rather the expertise and intuition of some engineers than the hydrodynamics theory. This design practice has changed in the last two decades, and fluid mechanics theory is increasingly applied, thanks to the huge rise of computing power and the available commercial and open-source tools. Today, most large manufacturers make use of modern Computational Fluid Dynamics (CFD) software in order to analyze and study in detail the flow field development inside the turbines, to test possible design modifications in the computer. Their design sector is staffed by skilled and competent engineers and designers, who have studied numerical modeling and graphical representation method, and are able to use complex computer software or even to develop customized computer algorithms. Powerful numerical design optimization tools, also developed in recent years, allow the simultaneous variation of numerous design parameters of the turbine (e.g. rotating blades and guide vanes shape, casing and meridian channels geometry), in order to achieve single or multiple objectives (e.g. maximization of energy efficiency and minimization of unwanted mechanisms like cavitation). Multipoint operation and unsteady phenomena, like pressure oscillations, are also modeled and controlled with the aid of specific software, whereas stress analysis tools are combined to improve manufacturing procedures and costs. The production efficiency of hydro turbines becomes a crucial feature today, not only for the net energy production and economic viability of modern hydropower plants, but also for the competitiveness and market penetration of turbine manufacturers. More and more customers-hydroelectricity producers are increasingly concerned, in addition to the mechanical performance and reliability of the machinery. (Perrig A, 2007) designed an Impulse turbines which is difficult, because of the very complex, unsteady, two-phase, free-surface during the jet runner interaction. This requires up to two orders of magnitude higher computer processing time per each simulation, than in a reaction turbine runner. Moreover, a number of complex and transient flow mechanisms are involved, like local flow separation and cavitations in the jet impact and bucket cut region, and the back-side flow, which are extremely difficult to be simulated and predicted in a reliable manner. Also, the structure of the jet emerging from the nozzle exhibits certain asymmetries due to the spear valve design and to secondary flows created in the distribution piping system. Jet surface degradation also appears due to interaction with the surrounding air, as also because of the impact of water droplets of runner outflow. For more than 20 years now CFD has been successfully used to analyze and develop reaction turbines (Keck, H. and M. Sick, 2008). However, modelling of impulse turbines like Pelton or Turgo is still a challenging task due to difficulties such as the pressure losses, secondary flows, jets, film flow, free surfaces, spray formation, ventilation losses, unsteadiness and complex interactions between components (Sick, M., et al., 2005) .Moreover, quasi-steady state approximations are not available for Pelton or Turgo turbine modelling which requires the use of completely unsteady time dependent simulations with rotor-stator interaction. Fortunately, despite the difficulties, the technology is advancing and some promising results are available.

The major components are the distributor, nozzle, runner and casing. The distributor and nozzle design affect the jet quality which is very important for both efficiency of the whole system (Staubli T., A.A., Weibel P., Bissel C., Parkinson E., Leduc J., Leboeuf F, 2009) and the operational life of the runner (Peron, M., et al.,2008 and Marongiu, J.C., P. Maruzewski, and E. Parkinson, 2005). The turbine efficiency is highly dependent on the bucket (Pelton) of blade (Turgo) geometry, which requires an accurate technique to model. The impulse turbine casing design is also very important as it might cause flow energy losses due to disturbance of incoming jets interfering with water sheets that have not evacuated (Staubli, T., et al, 2010). Simulation of the complete system that includes all the main sections is important but currently prevented by limiting factors such as the timescale or very high computational demands. For these reasons, compromises are introduced in order to achieve an optimum combination of accuracy and computational cost. The First CFD results of Pelton jet simulation were published (Sick, M., et al, 2000) by the end of the XX century and were followed by more publications later on (Parkinson, E., et al. 2002) Before CFD application, impulse turbines were developed using a graphical method (Brekke, H., 1984 and Hana 1999). Numerically modelled jet and bucket interaction (Kvicinsky, S., et al, 2002 and Parkinson, E., et al. 2006) appeared few years after the first free jet simulations were presented. These results looked promising in terms of CFD application of Pelton turbine development. However, only few publications present the design optimization based on numerical results. This issue regarding the absence of publically available numerically based and experimentally validated Pelton optimization results was addressed by Solemslie and Dahlhaug in 2012 (Solemslie B

MATERIALS AND METHODS

Equipment used

The principal instruments used for this construction are**;**

Multimeter, Tachometer, Marked Bucket, Vernier Caliper, Screw gauges. Measuring Tape, Hack saw, Bench vice, Hammer, Arc welding machine, Drilling Machine, Grinding Machine

CONSTRUCTION METHODOLOGY OF THE PROJECT

Mechanical Processes Involved

1. Preliminary design
2. Material selection
3. Manufacturing of parts by casting
4. Finishing using a Lathe m/c for produced parts
5. Drilling
6. Grinding
7. Cutting
8. Arc Welding/fabrication
9. Measuring
10. Rolling of galvanized metal sheet
11. Piping.

CALCULATION FOR DESIGNING THE PELTON TURBINE

Data obtained from project work

Diameter of the wheel, D= 24 cm = 0.24m

Diameter of the jet (coming from the nozzle), d= 4 cm = 0.04m

Artificial head from pump= 20 m

Step1: velocity of jet at inlet, $V1= C_{V}(2gH)^{1/2}$
C_v- coefficient of velocity (0.98 or 0.99) and H = Net head on turbine
$= 0.981*(2*9.81*20)^{1/2}$
= 19.4m/s

Step2: velocity of wheel/runner, $U= K_u(2gH)^{1/2}$
K_u = Speed ratio (varies from 0.43 to 0.48)
$= 0.46\ (2*9.81*20)^{1/2}$ m/sec
= 9.11m/s

Step3: RPM of the shaft, N= 60u/π D
= 60*9.11/3.142*0.24 rpm
= 725 RPM

Step4: Jet ratio, m= D/d
(D- pitch diameter of the Wheel, d- diameter of the jet)
= 0.24/0.04 = 6

Step5: Number of buckets, Z = 15 + D/2d
=15 + 24/2*4
= 18. (8 was used instead)

CONSTRUCTION PROCESS

In this process, suitable Aluminum scraps were Selected and melted, melted in order to get a suitable bucket cast of required specifications and size, patterns were formed, for both the bucket and the round bucket host using specified dimensions, considering allowances and other casting requirements, Cores were made to create the required shape inside the mold cavity, and the Melted metal was poured into the melted prepared core using a crucible, Finishing works were subsequently carried out on the cast to remove unwanted parts such as spurs. During the construction processes the cast turbine wheel of 24cm width and 2cm thickness was used and 8 holes in 2 array of 8mm diameter each equidistant to each other to hold tightly the base of the buckets was drilled .similarly, 2 holes of similar diameter (8mm) on the base of each bucket, spaced equal to the array spacing on the wheel to support and hold them firmly on the turbine wheel and buckets was bolted to the turbine wheel using an 8 sized bolt and nut, then a hollow circular mild steel bar of inner diameter 25 mm having a small amount of tolerance was fitted to the main center of the circular framed turbine so that it can be fitted to the shaft. The construction processes are shown in Plate 1

DESIGN OF THE FRAME:

Design of the frame is of great importance as it has to be manufactured in order accordingly with the design and scale of the project. The frame should have the capacity to hold the whole project firmly so that it could not fall break during the running of water or running of the Pelton wheel during its live

STEPS:

1. Starting the fabrication part of the project from the construction of frame. As shown in the below given diagram we cut the Trapezium-shaped base using angle iron cut into required dimension (in cm) with a hacksaw.
2. First by join the Angle irons into the specified dimension so that a robust base can be fabricated. For that process, we have joined and welded all the pre-cut galvanized iron bars of various dimensions by using arc welding process using 12gauge type electrodes. After the construction of the main base, we then cut the remaining metal to be fitted vertically into the base. For this purpose, also we have cut the bars and welded to the main base again by using arc welding method using 12-gauge type welding electrode.

CONSTRUCTION OF NOZZLE:

The Nozzles which are used to provide the high velocity jet coming out of the pump to the Pelton wheel was constructed to different sizes of nozzles. The diameters of the nozzles used are 20, 25, and 30mm respectively. For making converging nozzles two different sizes of cylindrical rods and cut it in machine into the desired sizes. Then both the rods are joined by using welding rods. We have used different types of nozzles so that we can vary the jet velocity of the water jet so as to obtain different values of rpm of the rotating Pelton wheel.

DESIGN OF SHAFT:

The shaft part, for which it was take a 35 mm diameter cylinder rod of 880 mm length. lathe machine was used to make the shaft as per required size. Operations like turning, facing were used to to achieve this. and a size 30mm shaft as per required for the pelton wheel part .To fit the shaft in the base frame and connect it to the alternator a bearing housing of internal diameter 20 mm of hole was used on the base. This bearing housing is used for the purpose of holding the main shaft to the frame rigidly. The bearing housing is held tightly with the main frame by using nuts and bolts of 10 mm diameter and length 1.5 inch.

TECHNICAL SPECIFICATION

Table 1:

PARAMETERS	VALUES
Alternator/Generator	60amps
Charging time	4 hrs.
Max. rotating speed	720rpm
Max. Head/pump capacity	20m/1HP
Turbine generation capacity	23V
Battery	12v

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PART LIST

Table 2:

S/N	PARTS	MATERIAL	DESCRIPTION	QTY
1.	2 point bearing	MS	2 point bearings	2 pieces
2.	Flexible Hose		θ $3\frac{1}{4}$ hollow hose	6 yards
3.	Turbine buckets	Aluminum cast	Spoon shaped buckets	8 pieces
4.	Solid shaft	MS	80cm length shaft	1 length
5.	Wheels	Silver steel	Tubeless wheel with push rings and castor wheels	4 pieces
6.	Electrodes	Alloy of metals	Consumable electrodes	30 pieces
7.	Bolts and nuts	MS	Hex Nut –8,13,14mm	8-16 pieces 13- 10pieces 14- 4pieces
8.	Angle Iron		Right angled MS iron	$2\frac{1}{2}$ length
9.	Drum	Galvanized metal	50cm Cylindrical drum	1 piece
10.	Nozzle	MS	Tapered circular orifice nozzle	2 pieces
11.	Square Metal clip	Metal sheet	15x11 cm metal with 4 holes of θ 4cm	4 pieces

TESTS, RESULTS AND DISCUSSION

After the successful design and construction process, two series of test were conducted on the turbine for performance evaluation considering the following criteria; workability, speed of rotation, electricity generation capacity and overall efficiency. A digital Tachometer was used to measure the speed of rotation, and a digital multi-meter was used in measuring the current voltage capacity generated.

TEST 1

The test was conducted with the initial turbine design setup having closely spaced shaft bearings, 8 turbine buckets and a 1 HP water pump of 20m head.

The first test conducted on the turbine revealed an initial design flaw in the positioning of the bearings and their relative spacing on the shaft. The picture below showing the initial design shows the closeness of the bearing arrangement on the shaft making it to wobble while in motion.

The first test also revealed an alternating rotational speed of the shaft with a constant jet issued from a single nozzle into the bucket ranging from a minimum value of 18.7 RPM to a value of 404.5 RPM

TEST TWO

The second test was conducted on the prototype impulse turbine, after the initial design was altered to increase the bearing distance from 24cm to 49cm. Also, the generator was mounted atop the shaft in the arrangement shown in the picture below. The turbine was made to run on a jet issued out from the nozzle of round orifice at a head ranging from a 10-20m (artificial head from a 1HP water pump).

The following observations were made (Discussion):

- As the Jet head increases, the rotational speed of the shaft spikes and the voltage reading of the generator increases considerably also.
- The nozzle positioned at the tip of the bucket, produces more force than when it strikes the center of the bucket.
- Increasing the bearing distance of the shaft gives more stability to the turbine in motion and reduces wobbling of the shaft considerably.
- The turbine produces little noise while in motion.
- With the arrangement used in the second performance test, the turbine at an increasing artificial water head (altered by increasing the pump speed), rotated at an RPM of 119.4- 223.5RPM, generating a voltage of 13.6 – 23.3V.

DISCUSSION

After all the required part of the prototype impulse turbine were completed, an alternator/generator was fitted to the main shaft of the rotating turbine vertically in-line and a proper cover was made for the turbine using a galvanized sheet metal to reduce head loss during rotation. After all the required parts were manufactured and fabricated, painting was done on them to curb the problem of rust and to also give the Turbine model an attractive look..

CONCLUSION

Results obtained from the performance evaluation tests conducted on the constructed Turbine showed that this device can be effectively used to proffer solution to the rising demand for a more efficient, reliable and economical ways of generating electricity for the many domestic and industrial needs of man, the construction of hydro turbines could be of great advantage affective alternative for electricity generation.

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Appendix



1. Aluminum cast 2. Furnace (Melting the Aluminum) 3. Placing the Pattern in the mold



4. After ramming the Mold 5. Removing the Pattern 6. Pouring the hot metal



7. Breaking the mold to remove Cast 8. Turbine Bucket cast 9. Turbine Wheel cast

Plate 2.Turbine wheel and buckets





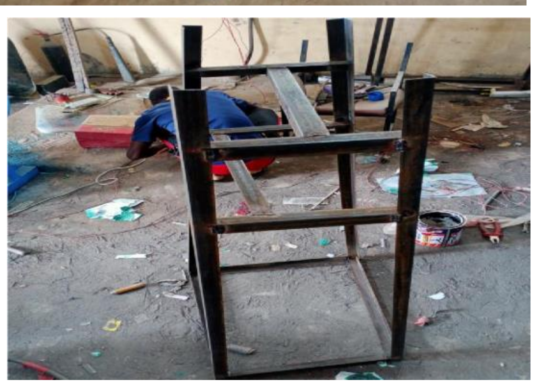


Plate 3: frame construction

Plate 3: Picture showing the Final result