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Simulation for Material Selection for a Pico Pelton Turbine's Wheel and Buckets

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Abstract

A Pelton wheel turbine is a type of impulse turbine that uses the hydro-mechanical energy of water at an elevated head into mechanical work which is then converted into electrical energy using an electric generator. The objective of this study is to design a Pico hydropower plant for supplementary power storage using the velocity of water harvested from rooftops during rainfall. Complete design calculations of the turbine have been performed as well as analysis of the model Pico energy device. Three types of materials considered most appropriate for the production of the model micro Pelton wheel and buckets are Steel, A390 cast aluminium alloy and Plastic due to availability and cost. The investigation was carried out using Autodesk Inventor to help select the most suitable based on the high cycle fatigue due to continuous force and displacements from the water jet. The materials performances were measured by von Mises stress, strain and displacement; and the result shows that an optimum performance of the wheel and Bucket without an undesirable level of failure in service was achieved using the Aluminum alloy.

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Keywords: Design; Micro Grid; Pico Turbine; Material Selection; Simulation.

1. Introduction

Hydropower (from the Greek word hydro, which means water) is energy that originates from the power of moving water [1]. Hydropower is known as a renewable vitality source on the grounds that the water on Earth is persistently recharged by precipitation [2]. Hydropower is a non-polluting process that utilizes high head of flowing

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water to generate electricity [3], [4]. The turbines are the machines that produce the Hydropower. A typical turbine possesses specially designed blades known as vanes or buckets that are driven by the power of moving water; the movement rotates a shaft connected to drive a generator [5]. Various types of turbines can be selected for hydropower generation based on the magnitude of the head and the condition of water flow available at the site [6]. The model of turbine designed in this article is a Miniaturized scale; which is rotated by a relatively low-pressure head usually referred to as Small Hydropower (SMH) turbines [7]. Pelton Turbines are found to be amongst the most suitable for a low flow power generation [8], [9]. Classification of hydropower can be summarized as below[10]. The material

Table 1. Categories of the Hydropower by Size.

Hydro Power Generation Size	Description
Large	Installations of **more than 1000 kW** capacity
Medium	Installations of between **15 and 100 MW** capacities
Small	Installations of between **1 and 15 MW** capacities
Mini	Installations of between **100 and 500 kW** capacities
Micro	Installations of between **5 and 100 kW** capacities
Pico	From a few hundred watts **up to 5 kW**

selection criteria for the low head hydropower turbine wheel are expected to satisfy the following conditions:

- Ability to produce a commensurately efficient quantity of electricity; comparing with the Velocity of the jet.
- Lightweight, cost-effective, locally available materials with an appreciable surface finishing ability.
- Having the mechanical and physical specifications needed for a prolonged service lifespan, possessing a natural corrosion- resistant and UV resistance ability [11].

2. Working Principle of the Pico Turbine Wheel Hydropower Arrangement.

The design strives on the procedure that the rainwater from the building rooflines are collected and runs through the downspouts to a raised tank and then the height of the bottom of the tank contribute enough head (pressure) to spin that turbine and thus generates a Pico energy [12]. The Pico hydropower system utilizes the rainfall harvested to produce electricity by the means of a Miniaturised Pelton turbine directly coupled with a small, variable speed, electric generator protected with an automated regulator [11], [13], [14]. An inverter arrangement is provided in the plan to save the energy continuously until it is needed for a household small energy demand [8].

2.1. Overview of Components Pelton Wheel Turbine

Pelton wheel has its main components described with their functions below.

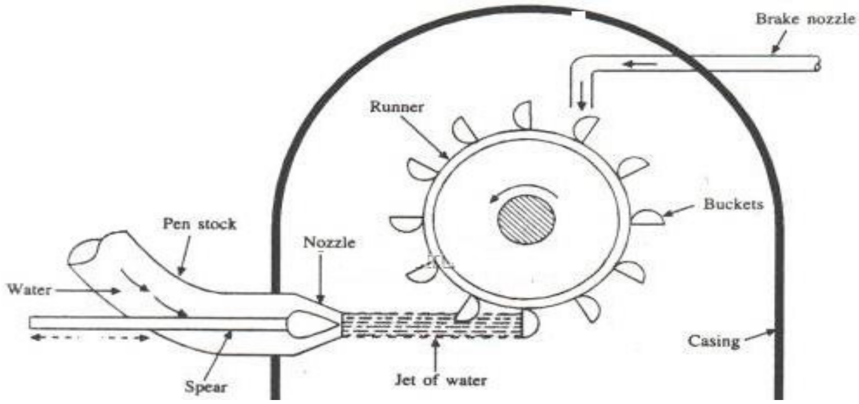

Fig. 1: Arrangement of a typical Pelton wheel turbine [5].

Nozzle and Flow regulating arrangement: A Pelton wheel nozzle is a guide mechanism used to control the water flow at the desired directions. A spear needle positioned inside the nozzle in an axial direction to regulate the flow of water through the nozzle. When the spear needle slides forward into the nozzle the area of the jet reduces and thus reducing the water quantity passing through the jet and vice-visa if the spear is being slid backwards. The regulation of the spear can be by automatic pneumatic arrangement [5].
Runner and buckets: Pelton wheel runner is a circular disc with a horizontal shaft passing through the centre. On the peripheral of the disc are buckets fixed at an equidistance. The bucket is a hemispherical cup with a divider known as a splitter at the middle which tends to split the water jet into two equal parts. The buckets are usually bolted to the runner disc but sometimes they are found a cast as a single unit. The inner surface of the buckets is expected to be as smooth as much as possible to aid the splitting of the jet and thus an efficient drive on the runner. It is advisable to have the buckets bolted to the runner disc for ease of replacement [1].
Casing: The Casing can be a metal or Plastic sheet covering provided around the runner of Pelton wheel. The casing is functional as a shield which does not perform any hydraulic function. The casing can be made of cast or fabricated parts [14], [15].
Braking jet: This is a nozzle arrangement provided such that directs the jet of water on the back of buckets tending to drive the runner in the opposite direction and thus resultantly acting as a brake to either reduce the speed of the runner or bring it to rest in a short time [1].

3. The Model Pico Hydropower System

Water is harvested from rooftops during rainfall and channelled into a tank on a stand at the side of the story building [16]. The tank discharges water through a pipe to the nozzle which then narrows the flow of water to the Pelton turbine [17]. As the water jet from the nozzle hits the Pelton turbine, it produces power to the shaft connected to the electric generator which then produces electrical power [2]. This system can be coupled with a power storage device which accumulates the small power the system produces. This Pico hydropower would be best used for very light domestic purposes. Below is a schematic diagram of how the Pico hydropower system is connected.

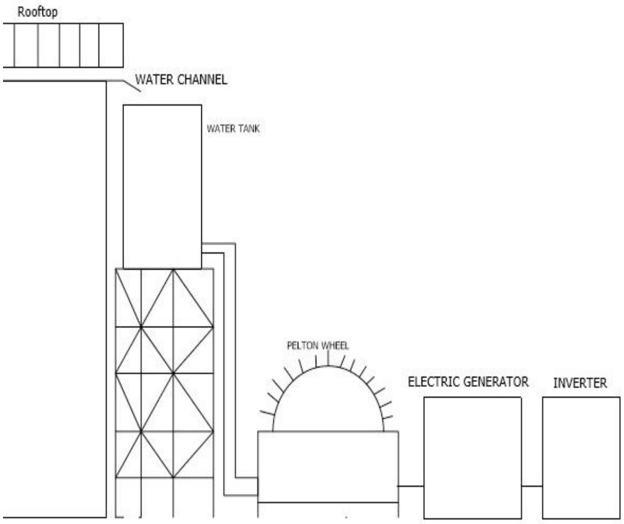

Fig. 2: Schematic diagram of how the Pico Hydropower System

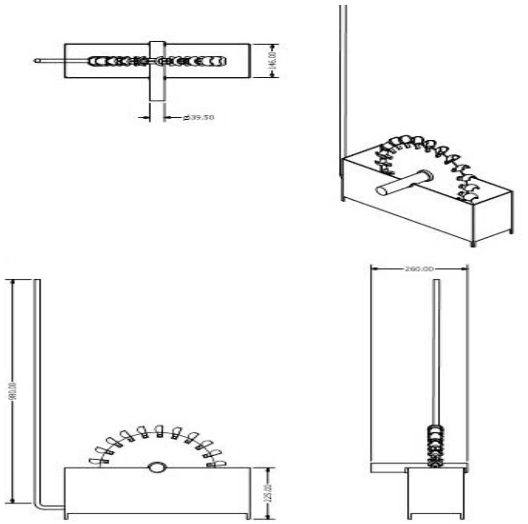

Fig. 3: The nozzle/Pelton Wheel arrangement

3.1. Design Specification of the model Pelton Wheel Turbine Components

The water falls from a head (H) at a flow rate (Q). The Pelton wheel is expected to run at a certain specific speed (Ns) to transfer torque (T) to the electric generator to produce a power (P) [18]. The expected output produced by the system is Power = 100W. The distance from the base of the collecting tank to the jet nozzle is considered to be a Head of 10m.

3.2. Design Parameters

Table 2: Parameters of the model Pelton wheel turbine as obtained from design Calculations

S/N	Parameters	Calculated
1	Flow rate, Q	0.01403 m^3/s
2	The velocity of the water jet through the nozzle	13.86m/s
3	The diameter of Pelton runner, D_r	0.3m
4	Bucket axial width	0.068m
5	Bucket radial length	0.06m
6	Bucket depth	0.024m
7	Number of buckets	22
8	The radius: centre of the bucket to the centre of the runner	0.141m
9	Runner tangential velocity	23.56m/s
10	Force on each bucket	11698.87N
11	Bucket roughness coefficient, Ψ	0.98
12	Deflection angle between bucket and jet, ϴ	160^0 to 170^0
13	The torque produced by the shaft	6.366N/m

4. Material Selection Analysis for the Pelton wheel.

The cost of producing the components of a Pico SHP is a major factor of consideration. The material for the fabrication of the Pelton wheel is most germane since other components for the construction of the mini plant: basically, various sizes of PVC pipes, couplings and plastic/metal sheet for case building are readily available in the local market at a various range of qualities and costs. Some market available Micro/Pico wheel available in the market were made of nylon resin embedded with fibreglass, Stainless Steel, Cast Iron and mild steel [19], [20]. However, making use of a less dense material for the wheel will mostly help in transmitting the jet velocity to a relatively higher Specific Speed thus higher efficiency [17]. Other materials that have been experimented with involves wood, Bakelite, ABS plastic, Aluminium based, advanced fibres and Composites materials amongst others [10], [17], [21], [22].

Three types of materials considered most appropriate for the production of the model micro Pelton wheel and buckets are Steel, A390 aluminium alloy (from recycling) and Plastic due to availability and cost. The investigation was carried out using Autodesk Inventor to help select the most suitable based on the high cycle fatigue due to continuous force and displacements from the water jet. Here the analysis can be done based on the linear static analysis. During the analysis, various justifiable assumptions were made and noted. The initial parameters were assumed to involve linear Static Analysis Inputs, the bucket maintains a uniform profile, the effects of external forces are negligible and the fixed arm acts similar to a cantilever beam. The analysis is carried out under two operating conditions: Torque = 636.6 Nm and Force = 11698.87N and the resulting effects of the applied force were indicated by the colour codes, as shown in Figure 4.

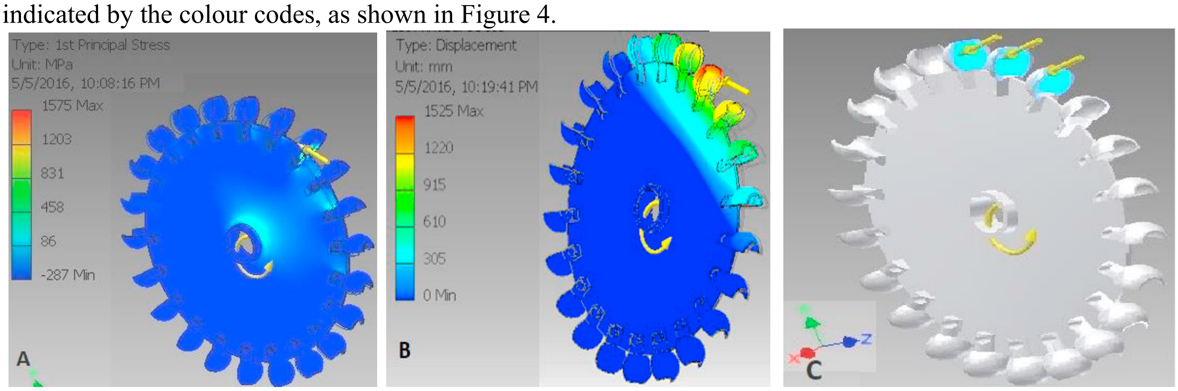

Fig. 4 (A): Analysis of Stress on the Pelton wheel Showing the Force. **(B)** Showing the displacement as a result of the acting forces **(C)** Showing forces on the preceding and receding buckets.

Table 3 below shows the analysis of the Pelton wheel with three different selected materials: Steel alloy, A390

Aluminium and Plastic with resulting physical properties.

Table 3: Physical properties of the Pelton turbine made of different materials.

Material	Steel Alloy	Aluminium Alloy	Plastic
Mass	3.26572kg	1.14068kg	0.557665kg
Area	277509mm^2	277509mm^2	277509mm^2
Volume	422474mm^3	422474mm^3	422474mm^3

Table 4: Table showing a summary of the analysis of the three different materials.

Materials		Steel Alloy	A390 Al Alloy	Plastic
Von Mises Stress (MPa)	Min	0.000102311	0.00135021	0.00226283
	Max	3188.49	1646.82	1864.56
1st Principal Stress (MPa)	Min	-571.143	-286.612	-496.091
	Max	1825.57	1575.47	1569.39
3rd Principal Stress (MPa)	Min	-2007.98	-1847.95	-2203.2
	Max	296.708	192.162	393.09
Displacement (mm)	Min	0	0	0
	Max	11.0786	23.0714	1524.52
Safety Factor (ul)	Min	0.0784069	0.166989	0.0536159
	Max	15	15	15

Plastic would have been the most cost-effective of all but for an indication from Table 4 and Figure 5 that it may fail in no time; this can actually be predicted for plastic decay as due to a significant response to displacement due to constant loading and exposure to some intense working conditions like exposure to UV ray over a period of time, etc.

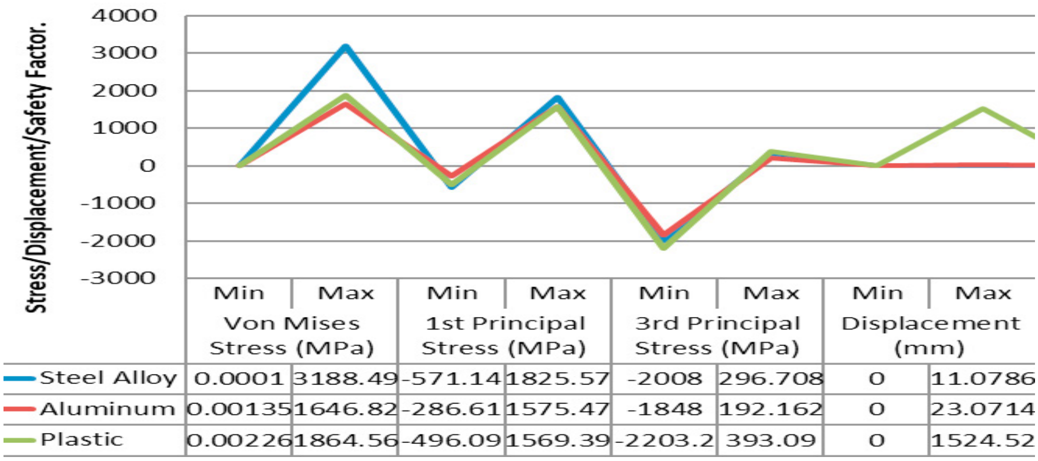

Fig. 5: Graph Showing the different materials of the Pelton Wheel under different Stress stages.

5. Conclusions

In a place like Nigeria, where the power supply is not readily available, attention had been on the microgrids as a supplement for the shortages. Most times the power supply needed for some functions like charging of cellular phones, lighting up the passages etc are not so bogus but very essential. These needs can be taken care of by making Pico-scale power supply which is stored and made use of when needed. This project successfully portray the design and simulation of a model of Pelton wheel turbine for a Pico size hydropower system that is to be driven by rainwater harvested from rooftops. However, the power supply depends on several factors such as availability of rainfall for sufficient water supply, Head and the storage capacity. The power produced by the Pico hydropower system is to be used as supplementary to reduce total dependence on the national grid. Recommendation for future research can be to investigate the possibility of developing a composite material that will be most suitable for a Pico Hydropower Turbine.

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