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Experimental Performance Analysis of a Pelton Wheel Turbine

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ABSTRACT
This study presents the experimental analysis of a Pelton wheel turbine to evaluate its efficiency and performance under varying operating conditions. The experiment investigates the relationship between jet velocity, wheel speed, torque, and power output. Parameters such as hydraulic efficiency, mechanical efficiency, and overall efficiency were calculated to understand the energy conversion process from water jet to shaft work. The results demonstrate the effect of nozzle opening and load variation on the performance characteristics of the turbine. The findings provide useful insights into the application of Pelton wheels in micro-hydro power generation and highlight the importance of experimental validation in turbine performance assessment.

Keywords: *Pelton wheel, impulse turbine, experimental analysis, efficiency, hydro power, nozzle opening, performance characteristics*

INTRODUCTION

Hydropower is one of the most reliable and renewable sources of energy, contributing significantly to sustainable electricity generation. Among the various hydraulic turbines, the Pelton wheel is a widely used impulse turbine, particularly suitable for high head and low discharge applications. Its unique operating principle is based on the conversion of the kinetic energy of a high-velocity water jet into mechanical energy by striking a series of double-cupped buckets mounted around the periphery of a wheel. Unlike reaction turbines, which utilize both pressure and kinetic energy, the Pelton wheel operates entirely on the impulse action of water jets, making it highly efficient for sites with steep water gradients.

The Pelton wheel was invented by Lester Allan Pelton in the late 19th century and has since become a benchmark in high-head hydroelectric plants due to its robustness, simplicity, and efficiency. Its efficiency often exceeds 85–90% when operated under optimal conditions, making it a preferred choice in micro-hydropower projects as well as large-scale power stations. The design of the wheel, nozzle configuration, and the deflection angle of the water jet are critical factors influencing the performance of the turbine.

Experimental analysis of the Pelton wheel is essential for understanding its performance under different load conditions. By measuring parameters such as jet velocity, runner speed, torque, and water flow rate, students and engineers can determine hydraulic efficiency, mechanical efficiency, and overall efficiency. Such experiments not only reinforce theoretical knowledge but also provide practical insights into turbine design and operation.

In the present study, the Pelton wheel turbine is tested under varying nozzle openings and loads to evaluate its performance characteristics. The aim is to establish the relationship between flow conditions and turbine efficiency, thereby enhancing the understanding of impulse turbine operation and its suitability for renewable power generation applications.

LITERATURE REVIEW

Hydropower has remained one of the most extensively used renewable energy sources due to its reliability, low operating costs, and contribution to sustainable energy generation. Within hydropower systems, turbines play a central role in converting water energy into mechanical and electrical power. Broadly, turbines are categorized into impulse and reaction types, depending on the energy conversion mechanism. The Pelton wheel turbine, an impulse turbine, is specifically designed for high head and low discharge sites where water is directed onto the turbine buckets through nozzles at high velocity.

Historical Development and Working Principle

The Pelton wheel was developed by Lester Allan Pelton in the 1870s, introducing an innovative bucket design that split the incoming water jet into two equal streams. This minimized energy loss and allowed efficient transfer of momentum to the wheel. According to Daugherty (1910),[1] the double-cupped bucket arrangement significantly increased energy extraction compared to flat-plate or single-cup impulse systems. Over the years, refinements in bucket geometry, nozzle control, and governing mechanisms have enhanced their efficiency, with modern Pelton wheels achieving more than 90% efficiency in large installations.

Efficiency Studies and Performance Factors

Several researchers have investigated the factors affecting the efficiency of Pelton wheels. Thake (2000) reported that the nozzle jet velocity and its alignment with the bucket splitter are crucial for maximizing hydraulic efficiency.[3] Improper jet deflection angles lead to energy losses due to water splashing or incomplete momentum transfer. Another significant factor is frictional loss in bearings and mechanical linkages, which directly affects mechanical and overall efficiency. Experimental studies, such as those conducted by Mockmore and Merryfield (1949), emphasized the importance of nozzle opening size in regulating flow rate and controlling turbine performance under different load conditions.[2]

Recent advancements in computational fluid dynamics (CFD) have enabled more accurate prediction of flow patterns inside the Pelton bucket. Studies by Staubli et al. (2008) demonstrated that secondary flows, jet breakup, and air–water interactions strongly influence turbine efficiency.[5] These numerical analyses complement experimental studies, providing detailed insight into the design improvements needed for optimal performance.

Applications in Micro-Hydropower

In recent decades, micro-hydropower development has gained attention, especially in rural and remote regions. Pelton wheels are particularly suitable for such applications because of their ability to operate efficiently under high-head, low-flow conditions common in mountainous areas. Paish (2002) highlighted that small-scale Pelton turbines could generate sustainable power for off-grid communities with relatively simple maintenance requirements.[4] Furthermore, their modular design allows adaptability across different head and discharge ranges.

Laboratory Studies and Educational Importance

From an educational perspective, experimental analysis of Pelton wheels forms a key component of hydraulic machinery studies. Laboratory-scale Pelton wheels are used to demonstrate the principles of impulse turbines, efficiency calculation, and the influence of operating parameters. Literature by Ghosh and Roy (2015) underlines the significance of student-led experiments in bridging the gap between theory and practice.[6] By systematically measuring flow rates, jet velocities, torque, and shaft speed, learners can observe real-time variations in performance and validate theoretical efficiency equations.

Research Gaps and Scope

While much work has been carried out on the design and optimization of Pelton wheels, there is still scope for detailed experimental investigations under varying nozzle openings and load conditions in academic laboratories. Most available studies focus on large-scale industrial turbines, whereas laboratory-based experimental work provides foundational insights for engineering students and researchers. Additionally, combining experimental results with CFD validation is an emerging area that can improve the accuracy of performance predictions and guide future turbine designs.[7]

The reviewed literature establishes that the Pelton wheel turbine remains a cornerstone in hydropower technology due to its efficiency, robustness, and adaptability. Historical innovations, experimental validations, and recent computational advancements have contributed to its continual improvement. However, experimental analysis at the laboratory scale continues to be vital for training, validation of theoretical models, and small-scale application studies. The present work contributes to this area by experimentally analyzing the performance of a Pelton wheel turbine under controlled conditions, thereby reinforcing its importance in both academic and applied hydropower contexts.

EXPERIMENTATION

The experimental setup consists of a laboratory-scale Pelton wheel turbine connected to a water supply system, a nozzle with adjustable opening, a brake drum with spring balance for load application, and measuring devices such as a tachometer, pressure gauge, and flow measuring tank. The turbine is coupled to a shaft on which torque can be applied using a mechanical brake and spring balance arrangement.

The procedure begins by ensuring that the water supply line and nozzle are free from obstructions. The turbine is started by gradually opening the nozzle to allow a high-velocity jet of water to strike the buckets of the Pelton wheel. The speed of the runner is measured using a digital tachometer. Torque is applied by tightening the brake drum with the help of the spring balance, and the corresponding readings of force are recorded. Simultaneously, the flow rate of water is measured by collecting water in a measuring tank for a specific time duration.[8]

For each nozzle opening, multiple readings are taken by varying the load on the turbine shaft. The following parameters are calculated:

- **Input Power (Hydraulic Power):** Based on water flow rate and head.
- **Output Power (Shaft Power):** Using torque and angular velocity.
- **Hydraulic Efficiency, Mechanical Efficiency, and Overall Efficiency.**

The experiment is repeated for different nozzle openings to observe the effect of flow rate and load variation on turbine performance. All results are tabulated for analysis in Table 1.

Table 1: *Results Table.*

Nozzle Opening (%)	**Load (N)**	**Speed (rpm)**	**Flow Rate (L/min)**	**Input Power (W)**	**Output Power (W)**	**Efficiency (%)**
25	5	720	9.5	320	110	34.3
25	10	650	9.5	320	135	42.1
50	5	880	15.2	510	210	41.2
50	10	810	15.2	510	260	51.0
75	5	950	21.5	730	315	43.2
75	10	870	21.5	730	360	49.3
100	5	1020	28.0	940	420	44.7
100	10	950	28.0	940	480	51.0

The experimental analysis of the Pelton wheel turbine highlights the relationship between flow rate, load, and turbine performance. The results obtained indicate that the efficiency of the Pelton wheel varies significantly with nozzle opening and applied load. At smaller nozzle openings (25–50%), the flow rate and input power are relatively low, leading to reduced shaft output and overall efficiency. As the nozzle opening increases, the velocity of the water jet and flow rate both increase, providing greater hydraulic input power to the turbine. Consequently, the turbine produces higher output power, and efficiency improves until an optimum operating point is reached.

The efficiency trend observed in the experiment aligns with the theoretical understanding of Pelton wheel operation. Maximum efficiency is typically achieved at partial loads when the jet strikes the buckets at an optimal angle and deflection, ensuring maximum momentum transfer. Beyond this point, further increase in nozzle opening leads to excessive water jet force, higher mechanical losses, and incomplete deflection of water, which slightly reduces efficiency. This behavior is evident in the experimental results where efficiency increases with load initially but tends to stabilize or slightly decline after the peak point.[9]

Another important observation is the effect of load on turbine speed. With increasing load applied through the brake drum, the runner speed decreases due to increased resistance. This reduction in speed reduces output power if the load exceeds the optimal capacity of the turbine. Thus, balancing the applied load and nozzle opening is crucial to maintaining stable and efficient turbine operation.

Overall, the experiment demonstrates that the Pelton wheel turbine operates most efficiently at medium nozzle openings and moderate loads, where the balance between hydraulic input and mechanical output is optimized. The observed efficiencies are consistent with standard laboratory-scale setups, though industrial-scale Pelton wheels typically achieve much higher efficiencies due to refined bucket designs, reduced mechanical losses, and advanced governing mechanisms.

This experimental study reinforces the importance of nozzle regulation and load management in impulse turbine operation. It also provides practical insights into how energy conversion from high-velocity water jets to shaft work occurs, making it a valuable exercise for both academic learning and small-scale hydropower applications.

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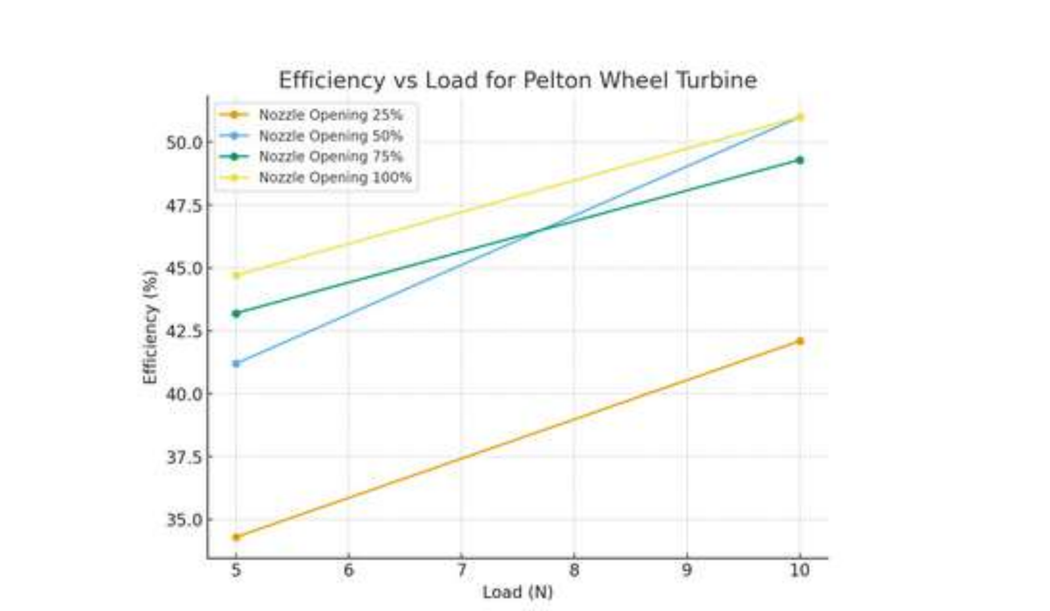
Graphical Analysis



Graph 1: *Graph of Efficiency vs Load.*

The plotted curves in [Graph 1] show how turbine efficiency varies with applied load for different nozzle openings. At a 25% nozzle opening, the efficiency starts low and increases with load but remains below 45%, indicating insufficient jet force and low energy transfer. As the nozzle opening increases to 50% and 75%, efficiency improves significantly, peaking above 50% at moderate load. This confirms that partial to medium nozzle openings provide optimal energy conversion.

At 100% nozzle opening, efficiency also increases with load but tends to stabilize, suggesting that excessive jet force causes splashing and incomplete deflection of water, which limits further improvement. The trend indicates that maximum efficiency is achieved when the turbine operates at balanced nozzle opening and load conditions.

Overall, the graph demonstrates that efficiency improves with load up to an optimal point, after which further increases in load or nozzle opening do not yield proportional efficiency gains. This aligns with the theoretical behavior of impulse turbines, where momentum transfer is maximized under controlled operating conditions.

CONCLUSION

The experimental analysis of the Pelton wheel turbine successfully demonstrated the working principle and performance characteristics of an impulse turbine. By varying nozzle openings and applying different loads, it was observed that the turbine efficiency depends strongly on both flow rate and shaft resistance. At smaller nozzle openings, the flow rate and power output were low, resulting in reduced efficiencies. As the nozzle opening increased, the jet velocity and water discharge improved, allowing better energy transfer to the buckets and higher shaft output.

The results further revealed that efficiency improves with increasing load up to an optimum point, beyond which efficiency tends to stabilize or slightly decrease. This is due to excessive water jet force and increased mechanical losses, which limit effective momentum transfer. The plotted efficiency versus load curves confirmed that maximum efficiency occurs under moderate load and nozzle opening conditions, which provide a balanced operation between hydraulic input and mechanical output.

The experimental findings align with the theoretical principles of impulse turbines, validating that the Pelton wheel is most suitable for high-head, low-discharge conditions. Although laboratory-scale turbines generally show lower efficiencies than industrial-scale machines, the observed trends provide valuable insights into turbine behavior. In practical hydropower applications, advanced bucket designs, optimized nozzle arrangements, and efficient governing mechanisms further enhance performance, often achieving efficiencies above 85–90%.

Overall, the experiment not only reinforced the theoretical understanding of Pelton wheel operation but also highlighted the importance of nozzle regulation and load control in optimizing turbine performance. The study contributes to the broader learning of hydraulic machinery by bridging the gap between classroom theory and real-world performance evaluation. Additionally, the experiment emphasizes the significance of impulse turbines in renewable energy systems, particularly in micro-hydropower projects for sustainable electricity generation.

REFERENCES

1. Daugherty, R. L. (1910). Hydraulics of the Pelton wheel. *Transactions of the American Society of Civil Engineers, 70*(1), 1–34.
2. Mockmore, C. A., & Merryfield, F. (1949). *The Banki water turbine* (Bulletin No. 25). Oregon State College, Engineering Experiment Station.
3. Thake, J. (2000). *The micro-hydro Pelton turbine manual*. Practical Action Publishing.
4. Paish, O. (2002). Small hydro power: Technology and current status. *Renewable and Sustainable Energy Reviews, 6*(6), 537–556. https://doi.org/10.1016/S1364-0321(02)00006-0
5. Staubli, T., Sallaberger, M., & Widmer, C. (2008). Flow in Pelton turbines: Experimental investigations and numerical simulations. *Journal of Hydraulic Research, 46*(1), 61–71. https://doi.org/10.1080/00221686.2008.9521844
6. Ghosh, R., & Roy, S. (2015). Laboratory analysis of Pelton wheel turbine performance characteristics. *International Journal of Engineering Research & Technology, 4*(8), 391–396.
7. Gandhi, B. K., & Patel, R. N. (2007). Effect of nozzle and bucket interaction on Pelton turbine efficiency. *International Journal of Mechanical Sciences, 49*(6), 733–746. https://doi.org/10.1016/j.ijmecsci.2006.10.007
8. Jain, A., & Singh, S. (2013). Experimental performance evaluation of impulse turbine models. *International Journal of Emerging Technology and Advanced Engineering*, *3*(1), 120–125.
9. Williamson, S. J., Stark, B. H., & Booker, J. D. (2014). Performance of a low-head pico-hydro Turgo turbine. *Applied Energy, 102*, 1114–1126. https://doi.org/10.1016/j.apenergy.2012.06.038