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A HOOPED PELTON RUNNER: FE ANALYSIS AND EXPERIMENTATION

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ABSTRACT

In the present work, stress analysis of traditional Pelton runner and hooped Pelton runner using FEA software ANSYS has been carried out. These results confirm the reduction of stresses in the Hooped Pelton Runner compared to Traditional Pelton Runner and the mechanical aspect as well as the results of the hydraulic comparison between traditional runners and hooped runners is made. An actual laboratory scale hoop runner based on this analysis and design is developed and the detailed experimental investigations are also carried out to prove the worthiness of this new design concept.

INTRODUCTION

Pelton turbine has been in use for more than 100 years and obviously belongs to the most important hydraulic turbines. Pelton turbines are used for the conversion of hydraulic energy in to electricity in mountain areas, where large altitude difference between water sources and sites of Pelton turbines exists. In special applications, the altitude, i.e. the hydraulic head even goes up to 1800 m.

The precise theoretical analysis of pelton turbines becomes more difficult due to a few peculiarities of the flow, such as: free jet flow and unsteady flow with free surface on the bucket. A specific aspect of pelton turbines simulation is the fact that due to periodic change of the relative position between the water jet and the bucket the flow is unsteady and has a free surface. Matthias & prost [1] attempted find criteria to estimate the influence of the splashed water distribution in the casing on the turbine efficiency and further they showed that the casing has great influence to the operation of a pelton turbine and so it is very important to include the casing as an important factor in all investigations.

The design of pelton runner, patented in 1880 by Lester Allen pelton, has changed very little but large technological changes have taken place from forged runner to separated buckets. Until recently, the most common design was one piece casting. The increase in performance led to a decrease of the ratio between the bucket width and the jet diameter, this led to an increase in loads and therefore an increase in stresses. At the same time, the inherent nature of cast steel led to the appearance on the market of forged and welded runners.

In terms of operation, little or no change occurred, as the maintenance of runners varied by sandy waters still leads to repairs by welding, followed by thermal treatments, and these operations leaves strains on the base material, and hence complete replacement of the runners. The current trend amongst operators is towards keeping maintenance costs and repairs to a minimum with higher component reliability. A new runner is proposed based on a separation of functions at the bucket level which allows a better distribution of forces without affecting the runner hydraulics. This runner is called the hooped runner and the stress distribution is studied in detail by Francois et. al [2]. The design of the hooped runner is intended to achieve easy maintenance, and the separation of functions at buckets and hoop which facilitates design optimization. This runner is composed of two half hoops and buckets. The definition of the attachment of the various elements to each other is obtained from the stresses transmitted to the various components. The attachment of the buckets is defined based on the centrifugal forces and the jet load. The bucket is modeled as an inner beam simply supported, resting on its central section and subjected to a force generated by a pre- stressed screw on the outer side. The centrifugal forces are completely taken up by a compound pin (hinge) fixed to the hoops. For the jet force, the screw load is multiplied by a lever arm effect so as to exert a contact load of the bucket to the rim that is much higher than that of the jet [3]. Figure 1 and figure 2 show the model of traditional runner and hooped pelton runner.

Good amount of literature is available on pelton turbine (Mohamed Farhat et.al. [4], Etienne Parkinson et al. [5], Alexandre Perrig et al. [6], J Cmarongiu et al. [7], T.Maitre et al. [8], Filip Sadlo et al. [9], Han Feng-qin et al. [10], T. Staubli et al. [11], Zh. Zhang et.al [12]).

In the present paper, the stress analysis and the experimental investigations are carried out on traditional pelton runner and hooped pelton runner. From the stress analysis results, the stress induced in hooped pelton runner is very less compared to the traditional pelton runner. The new concept of pelton turbine is created using simple interchangeable components, making maintenance easier without affecting hydraulic performances. Comparison of performance parameters is carried out for the designed hooped runner and traditional runner.

STRESS ANALYSIS

In a Traditional runner, the bucket is modelled as a cantilever beam subjected to a force generated by the jet. These alternated forces lead to fatigue stresses. Due to the geometry of the bucket, the seat of these stresses is in the connection radius between the rim and the centre edge in the upper part of the bucket thereby generating traction stresses.

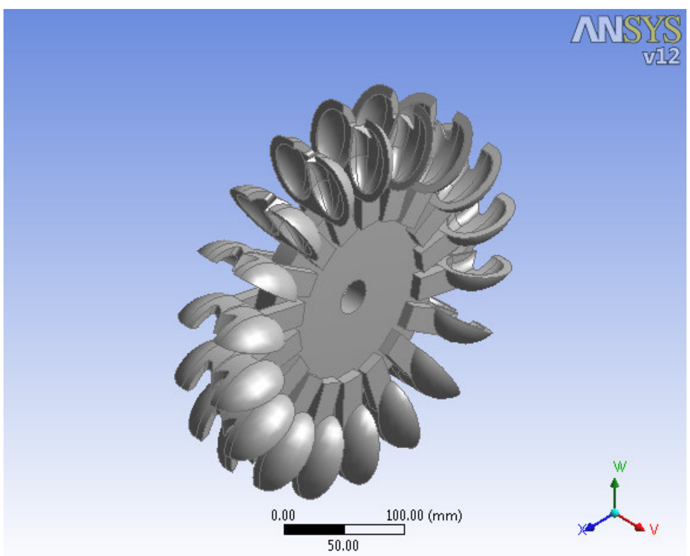

Figure 1 Traditional Pelton Runner

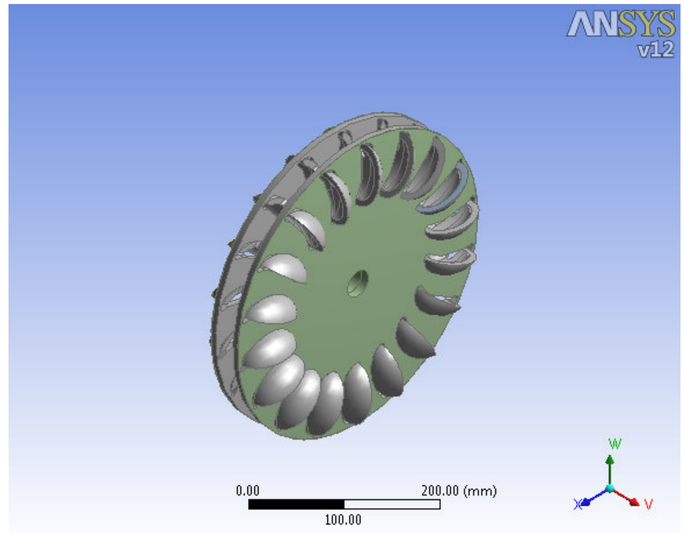

Figure 2 Hooped Pelton Runner

In a hooped runner, the arms are modelled as embedded beams. This configuration allows a decreasing of stresses on the most stressed zone and the transformation of traction stresses by compression stresses, as the geometry of the discharge radius is inverted. Dynamic stresses induced by excitation caused by the jet on the bucket are superimposed on static stresses due to the jet force. Measurements made in situ on classical runners in operation, by placing stress gauges in the stressed zones, show that the level of vibratory stresses is statistically of the order of 40% in buckets of classical one-piece Pelton runner [13, 14, and 15].

Static analysis of the Pelton runner loaded by the jet and centrifugal force was performed in order to investigative steady stress distribution at the runner using Finite element method. Since the runner is does not represents the periodic system, as the jet force is acting on one bucket only the structure periodicity was not taken into account when creating FE model. The three-dimensional grid independent study was carried out with number of nodes varying from 75,000 to 1, 60,000 nodes. The simulation results do not vary comprehensively between nodes of 79,931 to 1,52, 807 and hence a grid with 1, 25,934 nodes was selected for simulations, which is shown in figure 3 and figure 4.

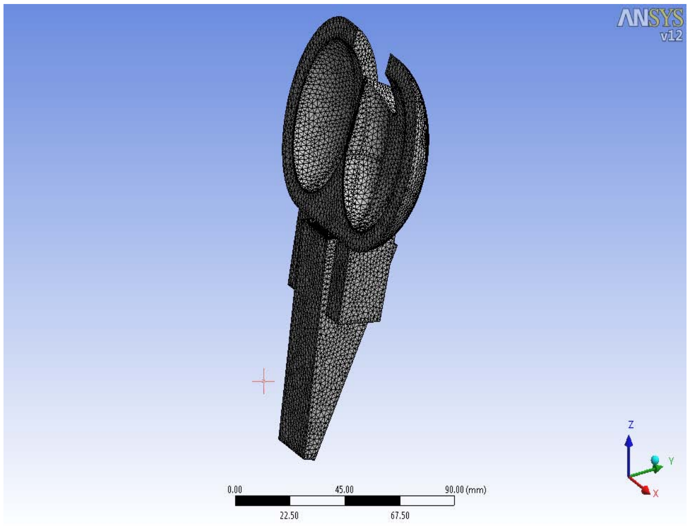

Figure 3 Mesh of traditional Pelton Runner

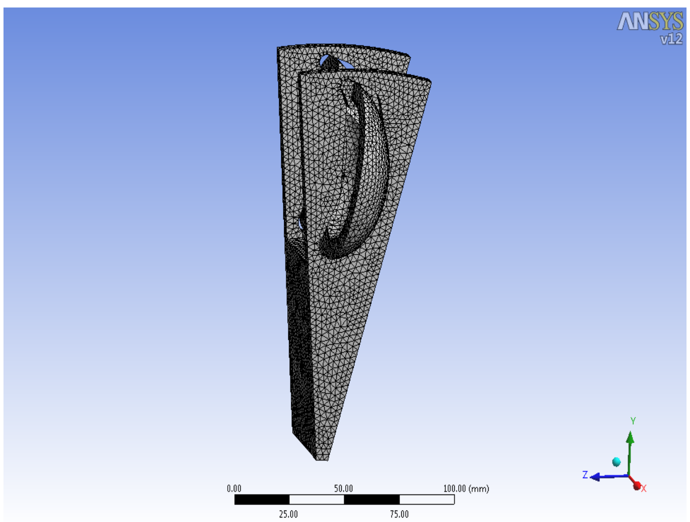

Figure 4 Mesh of Hooped Pelton Runner

Elasto-plastic material behavior was set in order to get the real stress distribution at the runner bucket. The calculation hypotheses are based on an 18 buckets machine under a 45 m head, with a particularly high rated speed of 1000 rpm jet arranged at 72°. The large scale of the calculation carried out has allowed all the development constraints to be integrated in a single model (accessibility, assembly, loading, etc.) and provides a mechanical model similar to the real runner like supporting centre area of the bucket on the hoops under the water jet.

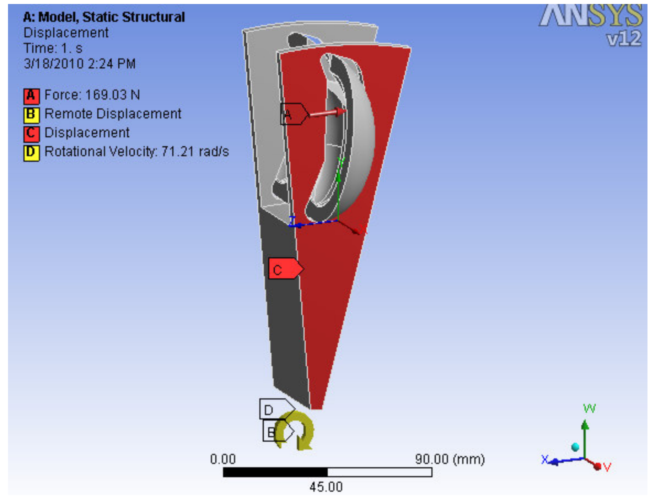

Figure 5 Constrains given to Pelton wheel

Submodeling technique had to be utilized to obtain correct magnitudes of the local stresses specifically at the curved dovetail where most the stress concentrations exist.

RESULTS AND DISCUSSION

Structural behavior:

Displacements results prove the validity of the concept. Calculation at synchronous speed shows the participation of the entire hoops to support the water jet forces. The tangential displacement of the hoops is global. Its value on the outer diameter in the non-loaded area is still more than half the maximum value on the opposite side within the jet influence. Figure 6 and 7 shows this tangential displacement of Traditional and Hooped Pelton runner at synchronous speed

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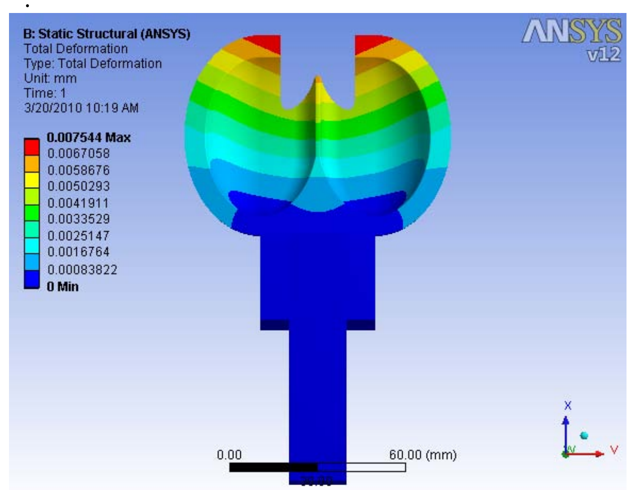


Figure 6 Tangential Displacement of Traditional Pelton wheel

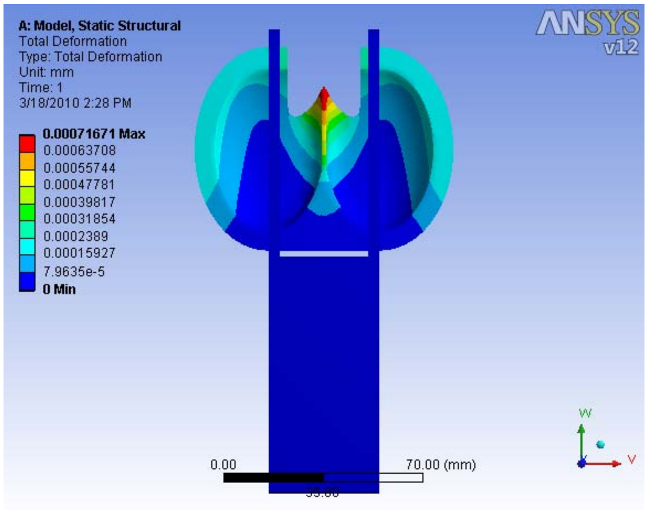


Figure 7 Tangential Displacement of the hooped Pelton wheel

STATIC STRESS

This distribution of the water jets forces on the entire hoops involves a decrease of the stress level in the runner. The figure 8 and 9 shows the equivalent stress distribution (VON MISES) at synchronous speed in the structural parts of the runner, it means on Traditional and Advanced Pelton runner.

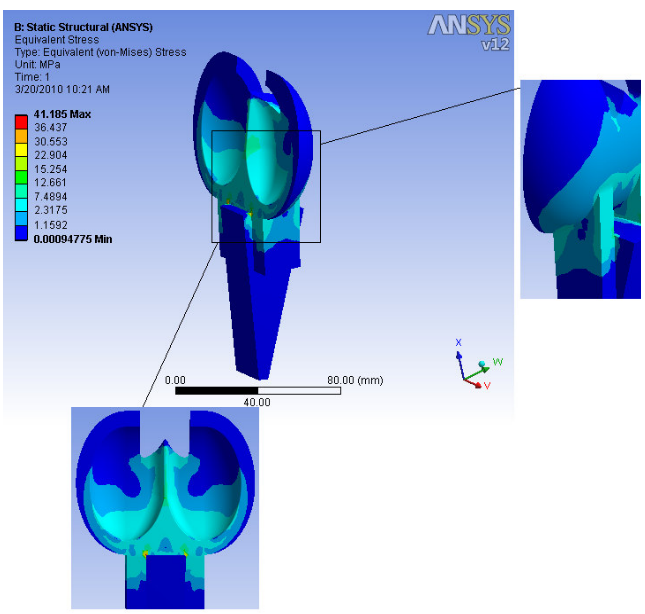


Figure 8 Equivalent Stress developed in the Traditional Pelton wheel

The main part of this stress is a static traction stress created by the centrifugal forces (rotation at synchronous speed). It is localized in the internal radius of buckets' opening, at the intersection with the buckets' internal attaches. The maximum VON MISES stresses are 41.185 N / mm^2.The Maximum stresses are localized at the connection of rotor disc and blade.

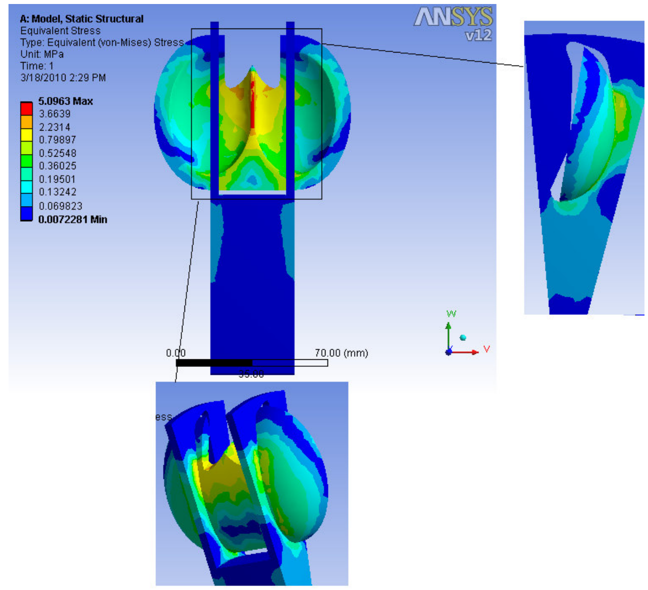


Figure 9 Equivalent Stresses developed in the hooped Pelton wheel

This distribution of the water jets forces on the entire hoops involves a decrease of the stress level in the runner. Figure 9 shows the equivalent stress distribution (VON MISES) in the structural parts of the runner, it means the hoop which is 5.09 N / mm^2 and 87.65% less compare than the traditional runner. The Maximum stresses are localized at the point where the jet is striking to the bucket. The distribution of stress shows that whatever the stress generated in rotor is distributed on hoop. Bernard Michel at el (3) on his studies on hooped Pelton runner had found the stress distribution on hoop.

DEVELOPMENT OF HOOPED PELTON RUNNER

The separation of the functions between buckets and hoop limits the shape complexity only to the hydraulically constrained surfaces of the individual buckets: no more highly 3D progressive fillets required to decrease stress concentration at bucket attachment. The bucket may thus be obtained from small foundry pieces, and their hydraulic profile generated precisely by NC- machining. The fabricated bucket is shown in Figure 10 while the front view of the forged hoop is shown in Figure 11. Hoops are either obtained from forged stainless steel disks or from high quality stainless steel plates. The hooped runner is developed as per the laboratory scale runner fabricated from mild steel.

Figure 10 Fabricated Bucket

The Hooped Pelton Runner developed as discussed in this section is shown in Figure 12. The designed Hooped Pelton Runner has 18 buckets with runner diameter of 360 mm.

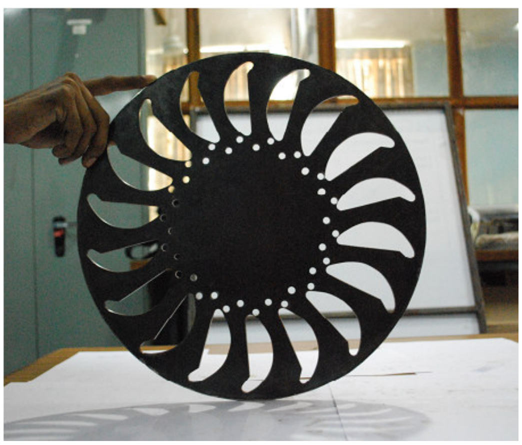


Figure 11 Front View of Forged Hooped

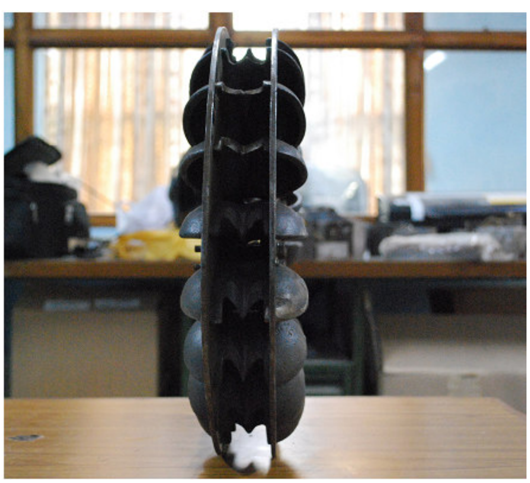
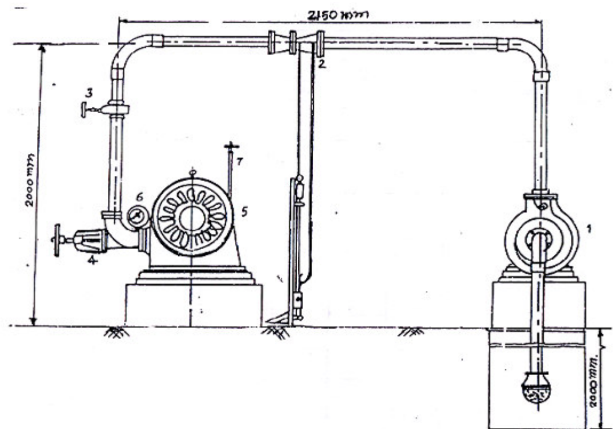


Figure 12 Hooped Pelton Runner

EXPERIMENTAL SETUP

The schematic view of the experimental test setup is shown in Figure 13. The single jet with diameter of 260 mm and maximum possible head of 45 m is used to experimentally evaluate the laboratory scale traditional Pelton Runner and Hooped Pelton Runner.



1	2	3	4	5	6	7
Pump	Venturimeter	Valve	Spear	Casing	Pressure gauge	Manometer

Figure 13 Schematic Diagram of Hooped Pelton Turbine Test Rig

The flow rate is controlled by nozzle percentage opening. The power developed is measured by rope brake dynamometer at different loads and nozzle percentage opening. The flow rate is measured using Venturimeter with coefficient of discharge of 0.96.Figure 14 and Figure 15 shows the Traditional Pelton Runner and Hooped Pelton runner fitted at the Experimental Test Rig, respectively.

Figure 14 Traditional Pelton Runner Fitted At the Test Rig

The two lateral hoops are separated from each other by the width of the front lips thus allowing the jets to reach the pressure side and spread into the buckets. Water then laterally flows out through the openings of the Hoop. The challenge is the optimization of buckets and the Hoop openings to avoid water interference with the Hoop.

Figure 15 Hooped Pelton runner Fitted At the Test Rig

EXPERIMENTAL RESULTS AND DISCUSSIONS

The experiments were carried out on traditional runner and hooped runner for different nozzle openings ranging from 20 % to full opening with an incremental value of 20%. The brake rope dynamometer was used for varying the load from 1 kg to 13 kg with an increment of 2 kg. The results of power developed and efficiency are related to specific speed at different nozzle openings.

Figures 16 to 20 show the variation of power developed with specific speed at different nozzle openings of 20%, 40%, 60%, 80% and full opening, respectively.

The power developed increases with increase in specific speed for both the traditional Pelton Runner and Hooped Pelton Runner. Power output is lower for Hooped Pelton Runner compared to Traditional Runner except for the nozzle opening of 20% as shown in Figure 16. At 20% opening the power output for the hooped Pelton runner is similar to that of traditional runner. The similar results relating to non dimensional ratio of Power Produced to Optimum Power are reported by Francois et. al. [3]. Similar results are obtained at different nozzle openings of 40%, 60%, 80% and full opening as shown in figures 16 to 19, respectively. Probably the losses in hooped runner are higher at different nozzle openings compared to traditional runner. At higher specific speeds, the difference in power output for the traditional runner and hooped runner is more compared to that at lower specific speeds (shown in Figures 16 to 20).

This may be probably due to the interaction of the water with the hoop and hence at higher specific speeds the power output decreases for the hooped runner. This results suggest that the need for optimization of buckets and hoop to avoid interference.

This decrease in power output for hooped Pelton runner compared to traditional runner with increase in specific speed leads to lower efficiency of hooped Pelton turbine as depicted in Figures 22 to 25. But with nozzle opening of 20% (figure 21), the efficiency of Hooped Pelton runner is higher than that of Traditional Pelton Runner. This may be probably, because diffusion of jet at lower nozzle opening resulting in decreasing efficiency while hooped runner diffusion is strictly restrict in hoop therefore hooped runner has higher efficiency than the traditional pelton runner. The distribution of water between the buckets and hoop reaches optimum and hence higher efficiency for hooped runner compared to traditional runner. From this result, it is obvious that the initial shape of the hoops leads to an interference with bucket outflow. Some improvements of the hoops are therefore necessary to recover the performance level of a traditional pelton runner.

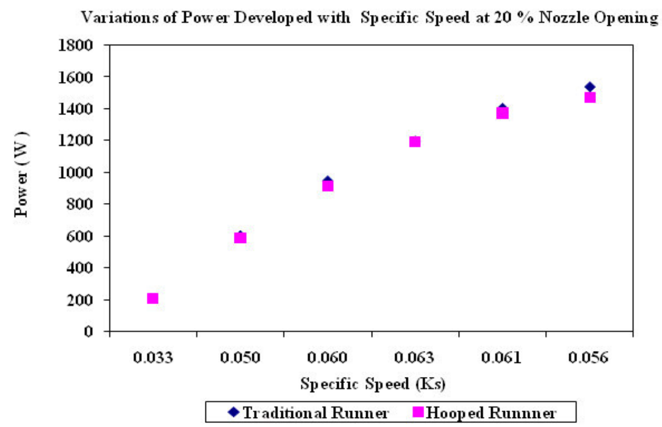


Figure 16 Variations of Power Developed with Specific Speed at 20% Nozzle Opening for Traditional Runner and Hooped Runner

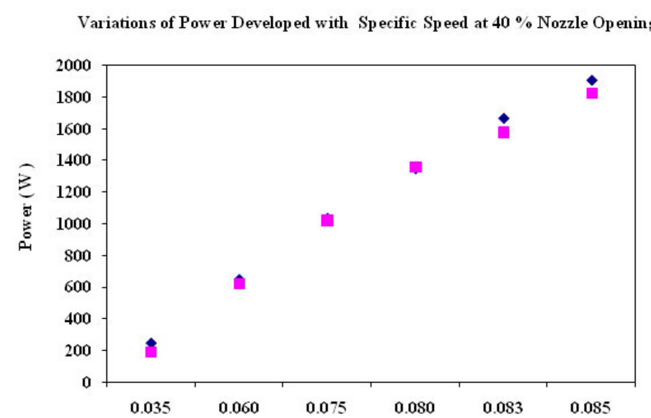


Figure17 Variations of Power Developed with Specific Speed at 40% Nozzle Opening for Traditional Runner and Hooped Runner

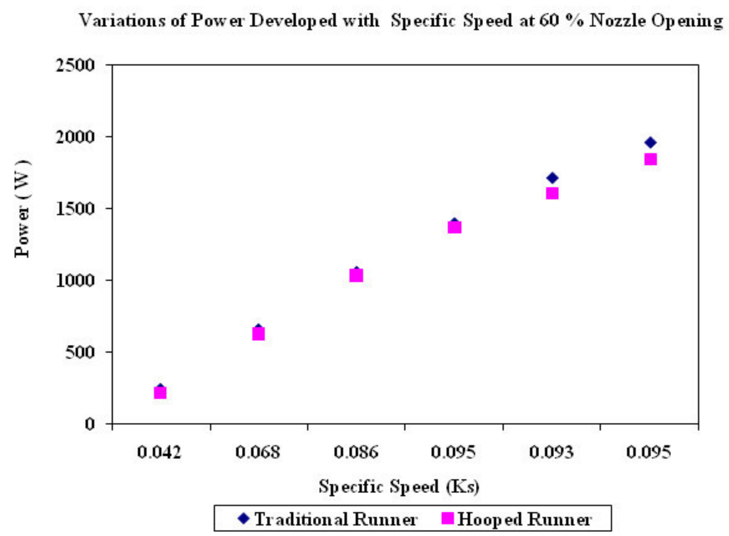


Figure18 Variations of Power Developed with Specific Speed at 60% Nozzle Opening for Traditional Runner and Hooped Runner

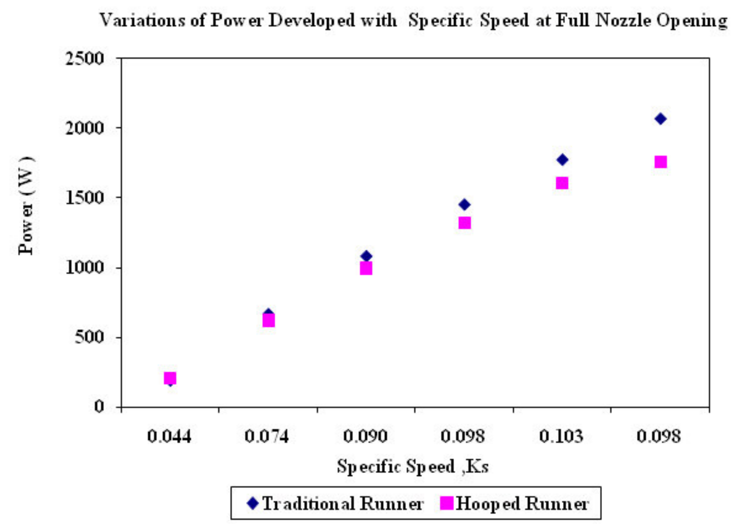


Figure20 Variations of Power Developed with Specific Speed at 100% Nozzle Opening for Traditional Runner and Hooped Runner

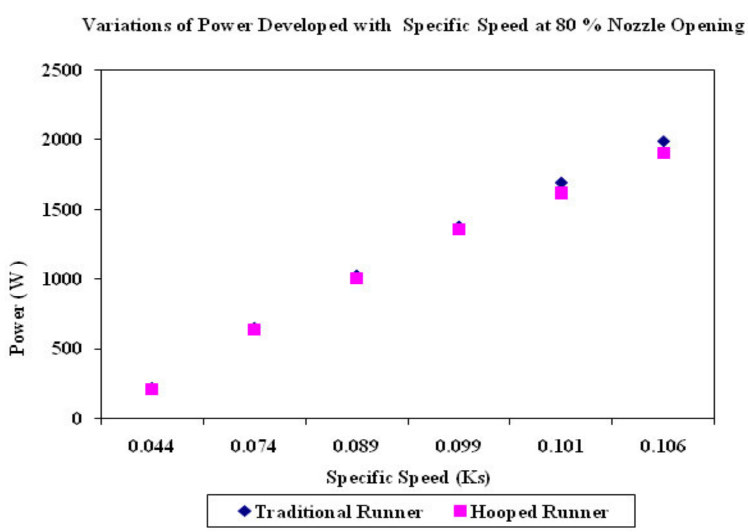


Figure19 Variations of Power Developed with Specific Speed at 80% Nozzle Opening for Traditional Runner and Hooped Runner

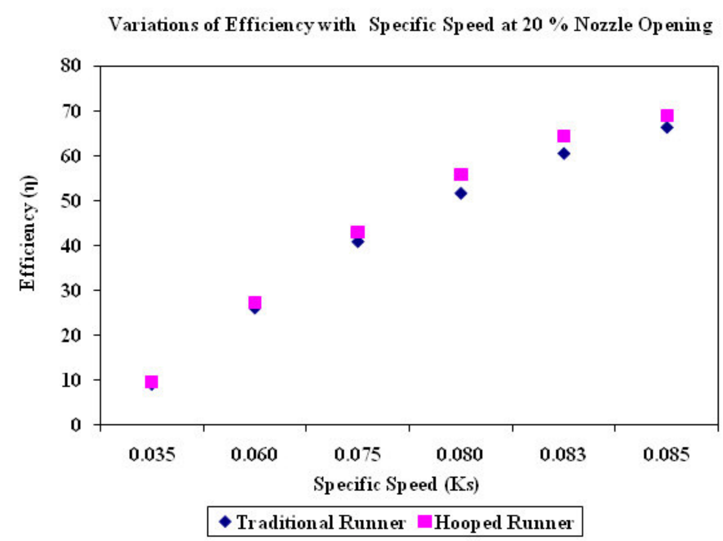


Figure 21 Variations of Efficiency with Specific Speed at 20% Nozzle Opening for Traditional Runner and Hooped Runner.

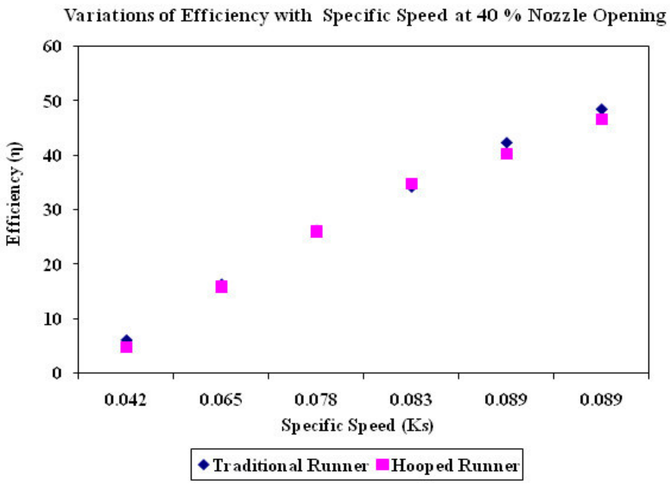


Figure 22 Variations of Efficiency with Specific Speed at 40% Nozzle Opening for Traditional Runner and Hooped

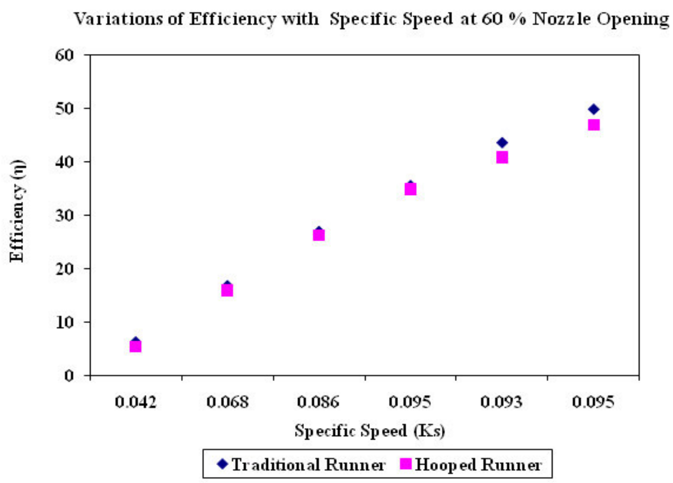


Figure 23 Variations of Efficiency with Specific Speed at 60% Nozzle Opening for Traditional Runner and Hooped Runner

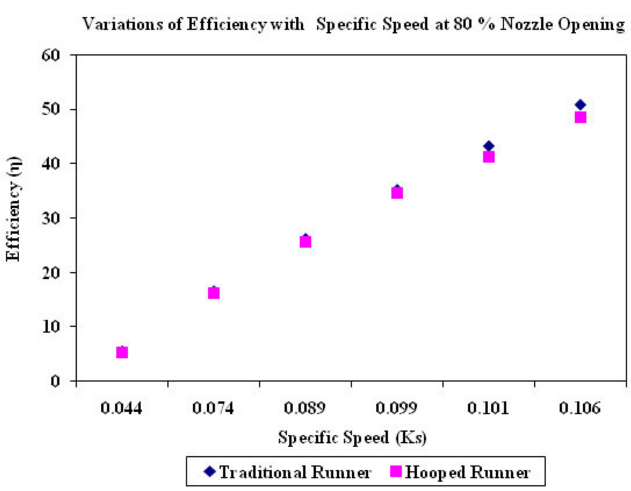


Figure 24 Variations of Efficiency with Specific Speed at 80% Nozzle Opening for Traditional Runner and Hooped Runner

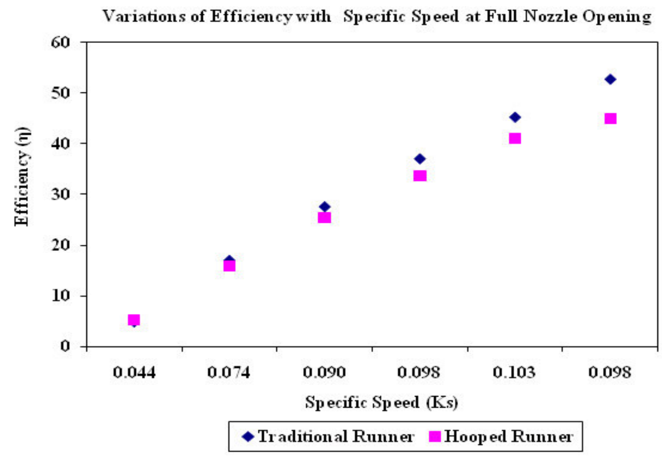


Figure 25 Variations of Efficiency with Specific Speed at 100% Nozzle Opening for Traditional Runner and Hooped Runner

CONCULSION

A new development in Pelton runner design, the hooped runner, based on the redistribution of functions between the buckets and the hoops. This allows the stresses to be minimized up to 87.65% and distributed more efficiently. The design is created using simple interchangeable components, making maintenance easier without affecting hydraulic performances.

A laboratory-scale Pelton turbine Test Rig is used for performance evaluation of an innovative concept of Hooped Pelton Runner. The experimental results suggest that the power developed and efficiency in traditional runner as well as hooped runner is nearly same up to the nozzle opening of 20%. But at higher nozzle opening the efficiency is lower for hooped Pelton runner compared to traditional runner. The achievement of new hooped runner design is based on the redistribution of functions between the buckets and the hoops. Hence the lower efficiency of the hoop runner may be due to the interaction of water with the hoop. This suggests that the Hooped Pelton Runner need to investigate using CFD approach and the interaction between the bucket and hoop be optimized.

NOMENCLATURE

V_{r_1}	Jet velocity relative to bucket at inlet
V_{r_2}	Relative velocity of the jet with respect to vane at outlet
m	Diameter ratio
Z	Number of Buckets
n_j	Number of Jets
D_m	Diameter of wheel
K_s	Non- Dimensional specific speed
u	Tangential velocity
C_v	Velocity coefficient

ω	Angular velocity of wheel
d_j	Diameter of jet
K	Relative velocity ratio
$\dot{m}$	Mass flow rate
N	Speed
P	Power
v	Inlet velocity
η_h	Hydraulic efficiency
θ_j	Bucket angular position

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