An Experimental Investigation of PAT in Direct and Reverse Mode at Turbine Testing Lab

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Abstract. PAT is typically employed as the electromechanical component, especially in the rural communities of developing countries in order to reduce the initial cost of a power plant. In the context of Nepal, there have been few researches about its feasibility but have given promising outcomes regarding its implementation. As a part of this continuation, this paper deals with the experimentation performed on end suction, KDS-520+ centrifugal pump of 3.5 kW on direct as well as reverse mode to study its performances. The main purpose of this study was to test the characteristic performance of the pump in turbine as well as pump mode to compare the variation in their efficiency in laboratory environment so as to shed light upon the importance of PAT in micro and mini hydropower and to study the prospect of replacing traditional water mills with PAT. The test rig for the operation of pump in turbine mode was developed as a part of the research and characteristic curves have been plotted on different flow rates. The efficiency of the centrifugal pump was found similar to the rated efficiency, 60.85% at the best efficiency point at the head of 17m and discharge of 17lps. In addition, performance of the same pump in turbine mode showed a maximum efficiency of 40.15% at flow of 11.5lps and head 10m which concluded that the centrifugal pump can operate in turbine mode without any modifications.

1. Introduction

Hydropower is probably the oldest renewable energy source known to the mankind for mechanical energy conversion as well as electricity generation. It is a renewable, non-polluting and environment friendly source of energy. It is inflation free source due to absence of fuel cost with mature technology along with highest prime mover efficiency and enormous operational flexibility [1]. Nepal is the second richest country in water resources with immense potential for Hydropower. Although hydropower is the primary source of energy in Nepal, there is still problem of electrification in the rural areas of Nepal.

Rural electrification plays a significant role in enhancing the quality of life for rural communities by promoting access to modern energy services. The traditional way to supply electricity to rural areas is to extend the national grid into these areas; however, after taking into account financial viability, this
approach is usually found to be uneconomical. Using micro hydro technologies for off-grid electricity generation is the most suitable method whenever there is an accessible potential site. The use of appropriate technologies to suit local conditions is one of the critical factors affecting the success of an off-grid micro hydro electrification system [1, 2]. Economic feasibility is one of the main considerations associated with micro hydro systems. Hence, the application of low-cost equipment for the micro hydro system has always been the central focus for rural electrification. [3]

In Nepal, mini and micro hydropower plant (MHP) is preferred due to large initial investment and longer payback period of large hydropower plants. Many micro and mini hydropower plants are established in which electromechanical (EM) components costs are higher. For micro-hydropower, the cost of EM components is 35 to 40% of total investment and 20% in large HPP [4]. Pumps have been used as turbine in different countries but Nepal as it has lots of benefits over the cost of electromechanical components comparing to turbines like Pelton, Francis or Kaplan.

In remote communities where it is not economical and practically possible to take the grid connection, stand-alone small hydro systems are used to fulfil the energy requirement. Small-scale hydroelectric power systems are emerging as a promising source of renewable energy generation, but they require low cost hydraulic and electric equipment to make them economically feasible as shown in figure 1. In such plants, pump can be used in turbine mode considering various advantages associated with pump e.g. ease availability, proven technology, low initial and maintenance cost, availability for wide range of head and flow etc [4].

In addition, there are nearly 100,000 'ghattas' operating all over the country but most needed to be upgraded to make them more efficient [5]. If only a tiny portion of this data of traditional water mills is replaced by PAT, proper utilization of the water resources along with upliftment of social and economic lifestyle of people residing in rural areas is possible.

This paper presents an experiment work which involved the testing of a centrifugal pump in a hydraulic test rig in direct as well as reverse mode. The hydraulic test rig was developed on the turbine testing lab. The main purpose of this study was to test the characteristic performance of the pump in turbine as well as pump mode to compare the variation in their efficiency in laboratory environment so as to shed light upon the importance of PAT in micro and mini hydropower and to study the prospect of replacing traditional water mills with PAT.
2. Past Research
Nourbakhsh and Derakhshan [6] have tested several centrifugal pumps with specific speed less than 60 (m, m³/s) and derived some relations to numerically predict the best efficiency point of pumps being operated as a turbine. They have also proposed a procedure to choose a centrifugal pump to be operated in turbine mode for small hydropower. Raman et. al. [7] have performed similar tests on an end suction centrifugal pump with specific speed 15.36 (m, m³/s). Their study conclude that pumps operate at higher head and discharge, but with lower efficiency, in turbine mode than its rated head and discharge in direct mode. Jain and Patel [4] have performed an extensive review of studies done on pumps running in turbine mode. Their review shows that single stage end suction centrifugal pumps are technoeconomically most compliant type of pump for use in turbine mode. Another state of the art review done by Binama et. al. [8] provides a bird’s eye view of the research done on use of pumps in turbine mode for off grid energy systems. According to the review, numerous studies have been carried out for the prediction of performance of the pump in turbine mode, however, no study have been able to determine the procedure applicable to a wide range of specific speeds. Even though PAT technology has been studied in many countries around the world, no such research has been done to implement this technology in Nepal.

3. Methodology
To achieve the objectives, a state of the art test rig with accurate and reliable instrumentation was developed in order to achieve the process of generating benchmark data. A centrifugal pump having closed radial impeller of Kirloskar Company model no. is KDS-520 + was selected to study the characteristics curve in pump as well as in turbine mode.

![Fig. 2. a) Pump in pump mode b) Pump in turbine mode [4]](image)

3.1. Pump Test Rig Main Component and Sensors
The main components consisted of a Pump, test bed, Piping network, Sump Tank, Butterfly valve and a Francis Turbine as a load dump. Figure 3 presents the schematic of the hydraulic test rig that was adopted for the Pump test.
The experimental setup for pump test consisted of a pressure gauge, flowmeter, butterfly valve, francis turbine load dump, sump tank and the pump to tested. The operating parameters were recorded by the Pressure transducer, Variable Frequency Drive (VFD), Pitot tube, Tachometer, Multi-meter and Power Analyzer. The pressure transducer was used to measure the suction pressure as these transducers when connected to an appropriate electrical source and exposed to a pressure source, will produce an electrical output signal; voltage, current or frequency, proportional to the pressure. To vary the frequency and voltage supplied to the electric motor, a VFD was used and the Pitot tube was utilized for the measurement of flow of the pump and the pressure difference. The test rig consists of six main components and sensors. A locally available end suction centrifugal pump was used for the experimentation process. TKDS-520+ model with rated power 3.75 kW having 2875 RPM and 12m Head was used during the experiment.

The piping connections were selected based on the suction and discharge diameter of the pump. Both inlet and outlet diameter of the pump was 80 mm Valves were used to control the flow of water into the runner. The control of flow conditions is vital for the experimentation of the pump on several operating conditions hence a butterfly valve was used during the process. The experiment was performed on the standard Francis test rig of 2 kW. The Francis turbine was utilized as a load dump to compensate the
high pressure discharge from the model pump. Tank was used to store water for the test and to provide support to the flow loop for consistent water supply.

3.2. **PAT Test Rig Main Component and Sensors**

Figure 5 shows the schematic of the hydraulic test rig that was adopted for the Pump test. The main components consist of a Pump, test bed, Piping network, Sump Tank, Butterfly valve and a Francis Turbine as a load dump.

[Fig. 5. Schematic view of PAT test rig]

The operating parameters were recorded by pressure sensors, flow meter, tachometer and mechanical braking system. Two pressure sensors were used to measure the inlet and outlet pressure, a flow meter for the measurement of the flow from PAT, a tachometer for measuring the rpm of the model pump and mechanical braking system was used to dump the load.

The PAT test rig consisted of the six main components. A pump of 250 kW power rating equipped with Variable Frequency Drive at Turbine Testing Lab was used to drive the PAT. High Pressure Tank pressurized the water in the tank to increase the velocity of the water coming from the tank to the pipelines and then the turbine. A reducer was present between high pressure tank and the PAT inlet so as to pass the water to the impeller. The diameter of reducer inlet was same as that of high pressure tank, i.e. 200 mm and the reducer outlet diameter was same as that of turbine inlet diameter, i.e.80 mm. The same model pump KDS 520+ tested in pump mode was used as PAT. The pressure gauges were placed at the inlet and outlet of the PAT. The pressure difference between the two points gave the pressure difference across the PAT and real-time flow rate of the water in the PAT was recorded using a digital flow meter.

Type B uncertainty for the flow meter and pressure sensors are 0.3% and 0.075% as mentioned in the user manual of both the sensors.

3.3. **Experimental Expressions**

For Pump in Turbine Mode, the outlet flow angle from the impeller in reverse operation is equal to the impeller inlet flow angle in direct operation the same Euler heads for both modes can be considered equal;
\[ H_{PE} = H_{IE} \]  

(2.1)

Velocity:
\[ V = C_v \sqrt{2g \Delta h \left( \frac{\rho_m}{\rho} - 1 \right)} \]  

(2.2)

Where,
- \( H_{PE} \): Pump Head
- \( H_{IE} \): Turbine Head
- \( C_v \): Coefficient of discharge
- \( g \): Acceleration due to gravity
- \( \Delta h \): Pressure drop

Euler equation:
\[ \eta = \frac{V_{zu} U_1 \pm V_{1u} V_{zu}}{gH} \]  

(2.3)

Power (\( P_t \))
\[ P_t = \frac{2\pi NT}{60} \]  

(2.4)

Torque
\[ T = (W_1 + W_3 + W_4 - W_2)gR \]  

(2.5)

Total Hydraulic Power developed:
\[ P = gQgH \]  

(2.6)

4. Results and Discussion

The efficiency of the pump is in compliance with the characteristic curve that comes with the pump from the manufacture as the efficiency decreases at both part load and full load conditions. Similarly, when the same pump is operated in turbine mode, the best efficiency point is obtained at a higher flow rate away from what was the BEP in pump mode as mentioned by in other studies of similar kind. The flow rate for the turbine mode could not be increased due to the smaller size of the pump used to run the turbine. However, the trend of the graph shown in Fig 7. implies that the efficiency would reach a crest at a certain flow rate and start decreasing beyond that, similar to that shown in Fig 6.
In order to understand the characteristic of the pump, a series of experiments were carried out. The efficiency of pump increases with the increase in flow rate at constant rpm. However, the head attained by the pump decreases at a much slower slow rate with increase in flow rate at constant rpm (shown in Fig 8 and 9).

**Fig. 8. Efficiency vs. Flow rate at various RPM**

**Fig. 9. Head vs. Flow rate at different RPM**

5. **Conclusion**
A KDS-520+ pump was experimentally tested to study the pump operating in turbine mode characteristics. Experiments performed at various operating conditions showed that a centrifugal pump could be effectively operated in turbine mode without any mechanical problems. In order to operate the pump in turbine mode, the head and discharge should be increased by a certain factor. These factors can be determined referring the graphs plotted for the range of specific speeds. At a constant rpm, the efficiency of the pump increases with the increases with the increase in flow rate upto a certain extent and start decreasing after reaching the best efficiency point. But, the head attained by the pump decreases at a slow rate with the increase in flow rate at a constant rpm.

The solution to the electricity crisis in the context of Nepal can be approached from a different perspective through the implementation of pump as turbine (PAT). With the recognition of the importance of PAT in Nepal, it is crucial to conduct more R&Ds to study the feasibility in the hydropower sector of Nepal. The maximum efficiency of pump was obtained 60.85% in direct mode and 40.15% in reverse mode showing a huge prospect of introducing PAT in mini and micro hydropower of Nepal and replacing traditional water mills with PAT.
6. References

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