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INSTALLATION AND TESTING OF A 5kW HYDROPOWER TURBINE

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ABSTRACT

This work focused on installation and testing of a hydro power turbine to generate 5 kW of energy for domestic applications. Water flows into the penstock $(pipe\ Ø600mm)$ from the dam at a height of 6m; the pipe diameter was reduced to $Ø200mm$ with a reducer socket. Water pressure decreases as it flows through the elbow joint. But such decrease or loss is recovered by a reduction of the pipe diameter to 80 mm and the pipe is long enough, (length = 2000mm) for the water to be fully developed before it enters the turbine at optimum speed. As the water flows through the runner of the turbine, its pressure reduces. The reduction imparts reaction on the runner and power is transferred to the turbine shaft. To prevent back flow or sucking back of water pressure into the turbine, a draft tube and a non-return valve are incorporated into the outlet of the turbine. The turbine shaft speed recorded with the aid of a tachometer is 298.33rpm and the dynamic pressure recorded at the turbine inlet, with the aid of a water pressure gauge is 170 kN/m^2. This gave an output power of 4.98 kW at a design flow rate of 0.106 m^3/s. The installation and testing of Francis turbine, pipe network and fittings were successfully carried out. It is obvious from the test results that the output power can power the street lights along Imo-street in the University of Ibadan, Ibadan, Nigeria.

Keywords: Hydraulics, turbines, Francis turbine, power, dynamic pressure.

INTRODUCTION

Hydro-electricity means electricity gotten from a water source. Hydro-electricity uses the potential energy of water falling from an elevated height to generate electricity. The potential energy in the water at the elevated height is converted into kinetic energy as it falls either freely in air or through pipes (penstock), into the turbine at a lower level. This difference in height known as 'head of water', plays a key role in hydro power generation. According to Muntean *et al.* (2010), hydropower is the largest source of renewable energy and it is the most efficient way to generate electricity. Hydropower is still the only means of storing large quantities of electrical energy for almost instant use. In hydro electric power plants, power is generated by the mechanical conversion of the potential energy present in water at a height into electrical energy by a turbine at a desirably high efficiency. The major component of a hydropower scheme include: dam or reservoir, penstock, turbine, slice gates, draft tube, and generator. The gravitational force causes the downward flow of water. At the beginning of the fall of water, the potential energy in the water due to its height is maximum, while its kinetic energy is at a minimum. The reverse becomes the case when the water gets to the turbine, since a large portion of the potential energy has been converted to kinetic energy. The water under high pressure enters the turbine, where the kinetic energy of the moving water with the aid of the increased pressure helps in turning the turbine runner. This results in a conversion of energy from kinetic to mechanical. A shaft is fixed to the runner which rotates with the same speed as the runner. Magnets are attached to the other end of the shaft, which spins around inside the coils of a conductor thereby converting the mechanical energy into electrical energy ready for distribution (Hands on energy discovery center, 2010).

Hydraulic turbine technology was first used by the primeval Greeks in constructing waterwheels. This knowledge was hitherto embraced in most of the ancient and medieval Europe in designing machines for grinding grains. The original design consists of a vertical shaft with a number of radial vanes also known as paddles. These paddles are positioned in a fast flowing stream (millrace). The reverse arrangement where the shaft is placed horizontally was first depicted by the Roman Architect and Engineer, Marcus Vitruvius Pollio during the 1st century B.C. This design had the lower portion of the paddle wheel inserted into the stream, hence acting as an undershot waterwheel. The hilly regions during the 2nd century AD started utilizing a more efficient overshot waterwheel. In this design, water was poured on the paddles from above, and additional energy was gained from the falling water. Smeaton John (1724 – 1792) as cited by Ajuwape and Ismail (2011) was certified with the earliest significant effort in formulating a theoretical basis for waterwheel design. Smeaton's theoretical calculations proved that the overshot wheel was more efficient, giving an efficiency of the water wheel of about 70%. Jean Victor Poncelet a French military engineer as by Microsoft student (2008 is credited with the undershot waterwheel design in which curve blades are used to increase efficiency to about 70%. Claude Burdin as cited by Microsoft student (2008) invented the term turbine. It was introduced as part of a theoretical discussion in which he stressed speed of rotation. Other researchers as cited by Adeyanju (2009) used the principle of the waterwheel to create the first turbine. Their work led to the development of a waterspout or nozzle that directs a high velocity stream of water against the blades set arranged on a wheel. This was huge stride away from the waterwheel. Wikipedia (2010) gave a vivid account of the gradual evolution of water wheel into the modern turbine. It reported that this advancement took about one hundred years. Pelton (1829 – 1908) as cited by Microsoft student (2008) was responsible for the development of a type of turbine, in which the water was piped from a high reservoir through a long duct or penstock to a nozzle where its energy was converted into the kinetic energy of a high-speed jet. The jet was then directed onto curved buckets, which turn the flow by nearly 180 degrees and extract the momentum of the impinging flow of water. Crewdson (1920) as cited by Ajuwape and Ismail (2011) improved on the work done by Pelton in order to obtain a higher efficiency. His work led to the development of the Turgo wheel, which produced higher efficiency and simpler construction than both the waterwheel and Pelton wheel.

James B. Francis as cited by Wikipedia, improved on Jean Victor Poncelet's designs and hitherto invented a turbine with about 90% efficiency. This high efficiency was achieved based on the application of scientific principles and testing methods in producing the turbine design. Chiefly was his mathematical and graphical calculation methods which improved the state of the art of turbine design and engineering. His analytical methods made way for self-assured design of high efficiency turbines which match various site's flow characteristics. The increasing demand for hydroelectric power during the early 20th century led to the need for a turbines suitable for small water heads of 3 to 9m that could be employed in many rivers where low dams could be built. Kaplan proposed a propeller turbine which basically acts like a ship's propeller in reverse. Kaplan later improved his turbine by allowing the blades to swivel about their axis. These variable pitch propellers improved efficiency by optimally matching the blade angle to the head or flow rate. Viktor Kaplan's work marked the advent of reaction turbines; unlike the water wheels and Pelton turbine which are regarded as impulse turbines, the Kaplan turbine is a reaction turbine. According to Energybible (2010), reaction turbines are turbines in which the runners are fully immersed in water and are enclosed in a pressure casing. The runner blades are angled so that the pressure difference across them creates thrusts, which cause the runner to rotate. Another type of reaction turbine that was developed around the same time as the Kaplan turbine is the Francis turbine (Adeyanju, 2009).

The Francis turbine

According to power electrical (2007), Francis turbine as shown in Plate 1 is an inward flow reaction turbine that combines radial and axial flow concepts. Francis turbines are the most common water turbine in use today. They are primarily used for electrical power production.

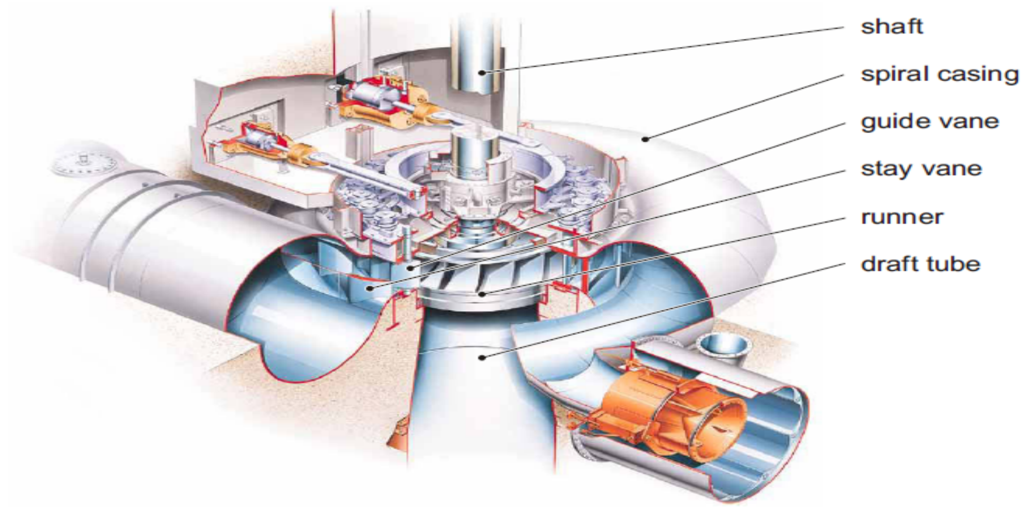

Plate 1: Francis Turbine

The Francis turbine is a reaction turbine, which means that the working fluid changes pressure as it moves through the turbine, giving up its energy. A casing is needed to contain the water flow. The turbine is located between the high pressure water source and the low pressure water exit, usually at the base of a dam. Guide vanes/wicket gates directs the water tangentially to the runner. This radial flow acts on the runner vanes, causing the runner to spin. The guide vanes or wicket gate are adjustable to allow for efficient turbine operation for a range of water flow conditions.

MATERIALS AND METHODS

Pipe sizing and design

Plates 2 and 3 below show assembly drawings of the pipe network for the hybrid plant. In order to prevent sudden contraction, a reducer socket was used to reduce the pipe diameter from Ø600mm to Ø200mm. A Ø200mm Tee joint pipe was then used to divert the flow upward towards the elbow joint while a sluice gate valve was used to regulate the flow on the Tee joint as shown in Figure 3 below.

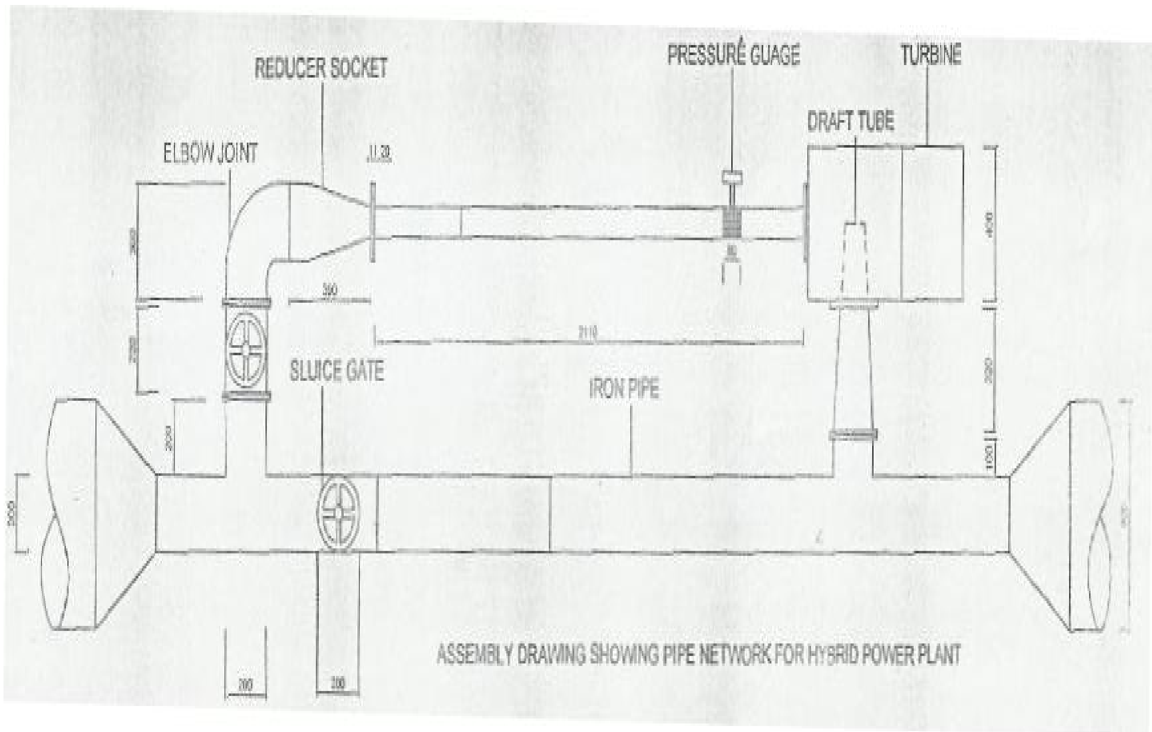

Plate 2. Showing the pipe network for the hybrid power plant (correct to read plate)

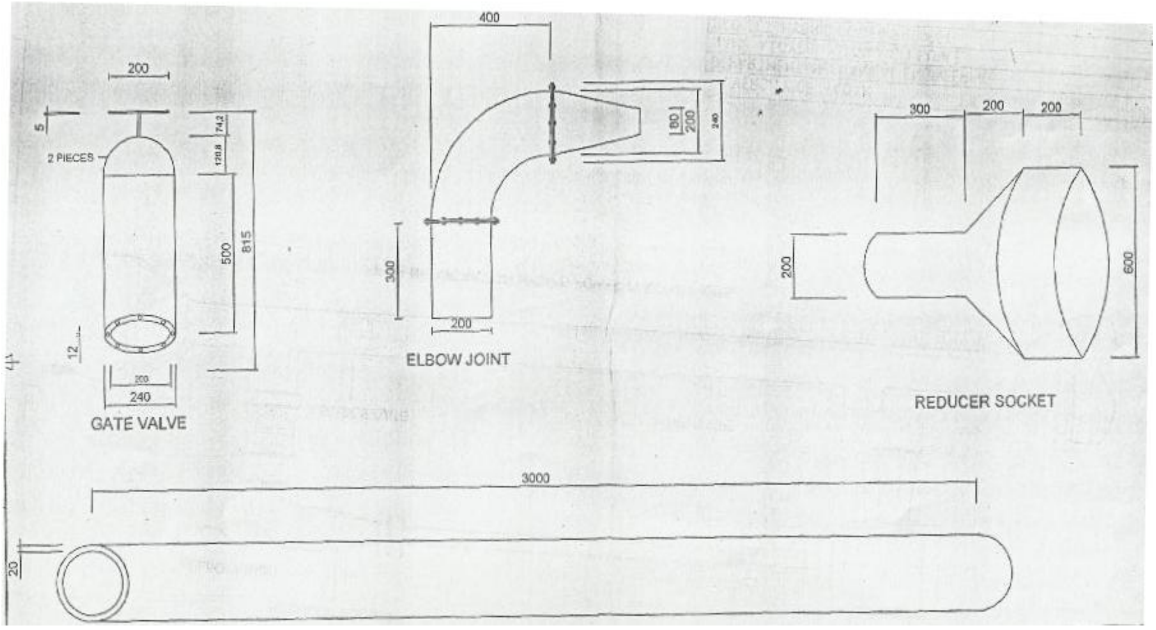

Plate 3: Showing gate valve, elbow joint and reducer socket (Similar correction above)

Generally, when water flows in a pipe, it experiences some resistances to its motion. This resistance has effect on the velocity of flow and ultimately the head of water available is reduced. The losses observed here are due to friction, sudden enlargement of pipe, sudden contraction of pipe, bends, obstruction in pipe, pipe fittings, loss of head at the entrance of the pipe and loss of head at the exit of the pipe. Losses were observed as water flowed upward to a height of 200mm via the Tee joint and then into the 90^0 elbow joint. The pipe was further reduced from Ø200mm to Ø80mm using a reducer socket. This will make the flow to be fully developed before the water enters the turbine thereby canceling out the effect of turbulence in the reducer socket. A draft tube and a non-return valve are incorporated into the outlet of the turbine to prevent back flow of water pressure into the turbine. To prevent sudden enlargement of the pipes, a reducer socket was used to connect the Ø200mm pipe to the drainage pipe (Ø600mm).

Design Calculations

The following design parameters were obtained during preliminary design process. The average head of the dam was estimated to be about 6m, using topographical survey instruments. The minimum power expected is 5kW, while the estimated flow rate and design flow rate are 0.244m^3/s and 0.106m^3/s respectively. The design speed of the turbine shaft was obtained to be 299.52 rpm. The turbine casing, draft tube design, wicket control mechanism, wicket control ring, turbine runner dimensions, turbine bearing and shafts were designed for using appropriate formulas obtained from Rajput (2008).

Installation of the turbine

In order to obtain higher productive output of turbine and its accuracy over a long period of service, the turbine must be installed on a solid foundation. The turbine was installed on a concrete floor, whose foundation weighed over 12 tons. The part that will be subjected to high dynamic loads such as shapers are made of concrete reinforced with steel net. The Francis turbine was installed with its axis in the vertical position. Some pipes were permanently welded while others were joined together using bolts and nuts. Rubber seals were also employed in joining and coupling of pipes and fittings to prevent leakages of both water and pressure.

Instrumentation

Three instruments were used during the testing of the turbine: the tachometer, pressure gauge and triple beam balance. A tachometer was used to measure the speed of the turbine runner shaft, while a water pressure gauge was used to measure the inlet pressure to the turbine. A triple beam balance was also used to measure the mass of runner and turbine shaft.

RESULTS AND DISCUSSION

Table 1 shows the value of the head dynamic pressure of water and speed of the turbine shaft for different positions of the valve obtained during testing of the turbine. The test results of pipe network and turbine gave a slight variation in speed of the turbine shaft when the head dynamic pressure was varied. An average pressure of 170 kN/m^2 and the average speed of the turbine shaft of 298.33 rpm of achieved.

Table 2 shows the results obtained from MATLAB codes written to scale up the project to a big hydro-power project and also provide detailed cost analysis of the hybrid project. The results obtained showed conformity with other previous hydro power projects.

Table 1: Test results of pipe network and turbine

	Number of measurements Carried out	Head dynamic pressure (P) Of water (kN/m^2)	Speed of the turbine shaft (rad/s)	Speed of the turbine shaft (rev/min)
1	Valve fully opened	170	30.37	290
2	Valve fully opened	180	29.32	280
3	Valve fully opened	160	29.85	285
4	Valve fully opened	165	30.05	287
5	Valve fully opened	170	32.46	310
6	Valve fully opened	175	33.51	320
7	Valve fully closed	150	29.32	280
8	Valve fully closed after 5 minutes	155	28.80	275
9	Valve fully closed after 10 minutes	150	24.61	235
10	Valve fully closed after 30 minutes	155	25.13	240

Table 2: Simulated Test results of pipe network and turbine for bigger hydro power plant

Discharge or Flow rate of Water (m^3/s)	Turbine shaft radius (m)	Mass of the turbine shaft and runner (kg)	Inlet pipe diameter to the turbine (x 10-3)m	Head, dynamic pressure of water (kN/m2)	Speed of the turbine shaft (rpm)	Power output of the turbine (kVA)
0.1060	0.0125	1300	80	222.310	299.52	5
0.2120	0.0250	2600	160	55.5879	599.12	40
0.4240	0.0500	5200	320	13.8969	1198.25	320
0.8480	0.1000	10400	640	3.47425	2396.49	2560
1.6960	0.2000	20800	1280	0.095234	4792.98	20480
3.3920	0.4000	41600	2560	0.21714	9585.97	163840
6.7840	0.8000	83200	5120	0.05429	19171.93	1310720
13.568	1.6000	166400	10240	0.01357	38343.86	10485760
27.136	3.2000	332800	20480	0.003393	76687.83	83886080
54.272	6.4000	665600	40960	0.000848	153375.45	671088640

CONCLUSION

This paper has presented and discussed the installation of a designed 5kW power Francis turbine. The overall electricity project was subdivided into various phases. The construction of the dam, design and fabrication of major components of the turbine such as spiral case, runner, guide vane etc. has been done separately in previous work. The various turbine components were coupled together, and the shaft speed and dynamic pressure measured. The turbine shaft speed recorded on the average of six measurements is 295.33 rev/min at a dynamic pressure of 170 kN/m^2 when the valve is fully opened. After 30 minutes of closing the valve, the turbine shaft speed recorded is 257.5 rev/min on the average of four measurements. Although a power output of 5 – 7 kW was designed for, at a flow rate of 0.106m^3/s, a power output of 4.98007kW was obtained. With the construction of a gear box (speed enlargement gear), turbine shaft speed can be further increased and this will increase the power output. Based on the results obtained above, it is evident that with minor re-adjustment of major design parameters, a 5kW of electricity will be constantly supplied from this hydropower project. In addition, the design parameters obtained using the MATLAB codes closely agreed with values obtained by previous Francis turbine designers. Hence, these codes can be used to easily scale-up the project to a bigger one.

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