DESIGN, FABRICATION AND TESTING OF REACTION TURBINE AND ITS TEST RIG

A Project Report

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ABSTRACT

Almost 89 percent of hydropower potential despite being the cheapest source of electricity generation is still untapped in Pakistan. The Khyber Pakhtunkhwa province has the huge capacity for installing of hydropower to generate maximum electricity, followed by Gilgit Baltistan as compared to rest the country, but the potential has not been utilized in a proper way to meet the growing energy demand in these provinces and rest of the areas. These facts were revealed in a study report on “Energy” prepared by Sarhad Chamber of Commerce and Industry (SCCI).

According to statistical data of the report, the total hydropower resources of Khyber Pakhtunkhwa are about 24,736 MW in various short, medium and long term projects, followed by Gilgit Baltistan with capacity of total hydro power generation of 21,125 MW. Punjab comes next with a total installed capacity of 7,291 MW, followed by Azad Jammu Kashmir (AJK) with capacity of 6,291. Despite efforts by both the provincial and federal governments, this vast hydro power generation potential from the country’s rivers and streams remains untapped. The aim of this project is development of a micro reaction turbine for utilization on wide range of heads. This would be micro scale project and hence would not require lot of capital.

Design Parameters of a Francis Turbine have been calculated, and test bed has been designed to study the performance of turbine. Turbine will have capacity to works on low head of 2 m and flow rate of 20 liters/second.

ACKNOWLEDGMENTS

We are thankful to our Creator Allah Subhana-Watala to have guided us throughout this work at every step whosoever helped us throughout the course of our thesis, whether our teachers or any other individual was Your will, so indeed none be worthy of praise but You. We would also like to express special thanks to our supervisor Dr. Muhammad Sajid for his help throughout our thesis and also for Fluid Mechanics courses which he has taught us. We can safely say that we haven't learned any other engineering subject in such depth than the ones which he has taught.

Finally, we would like to express our gratitude to all the individuals who have rendered valuable assistance to our studies.

ORIGINALITY REPORT

We certify that this research work titled "Design and fabrication of reaction turbine and its test rig" is our own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources is acknowledged and has been properly referred in the appendices of this report.

Muhammad Usama Khan | Shafaat Mushtaq | Muzammil Ijaz

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Dedicated to our teachers, friends and families whose tremendous support and cooperation led us to this wonderful accomplishment.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Francis turbine is an inward-flow reaction turbine that combines radial and axial flow concepts. It is designed for both high flow rates and high head. Francis turbines are the most common water turbine in use today. They operate in a water head from 40 to 600 m (130 to 2,000 ft) and are primarily used for electrical power production. The generators which most often use this type of turbine, have a power output which generally ranges just a few kilowatts up to 800 MW.

According to our need we are aiming to design and fabricate low head Francis turbine with the range of 100-300 watts. To test our turbine a test rig will also be installed which will have the water source, pump and dynamometer to measure the power of the turbine.

PROJECT METHODOLOGY

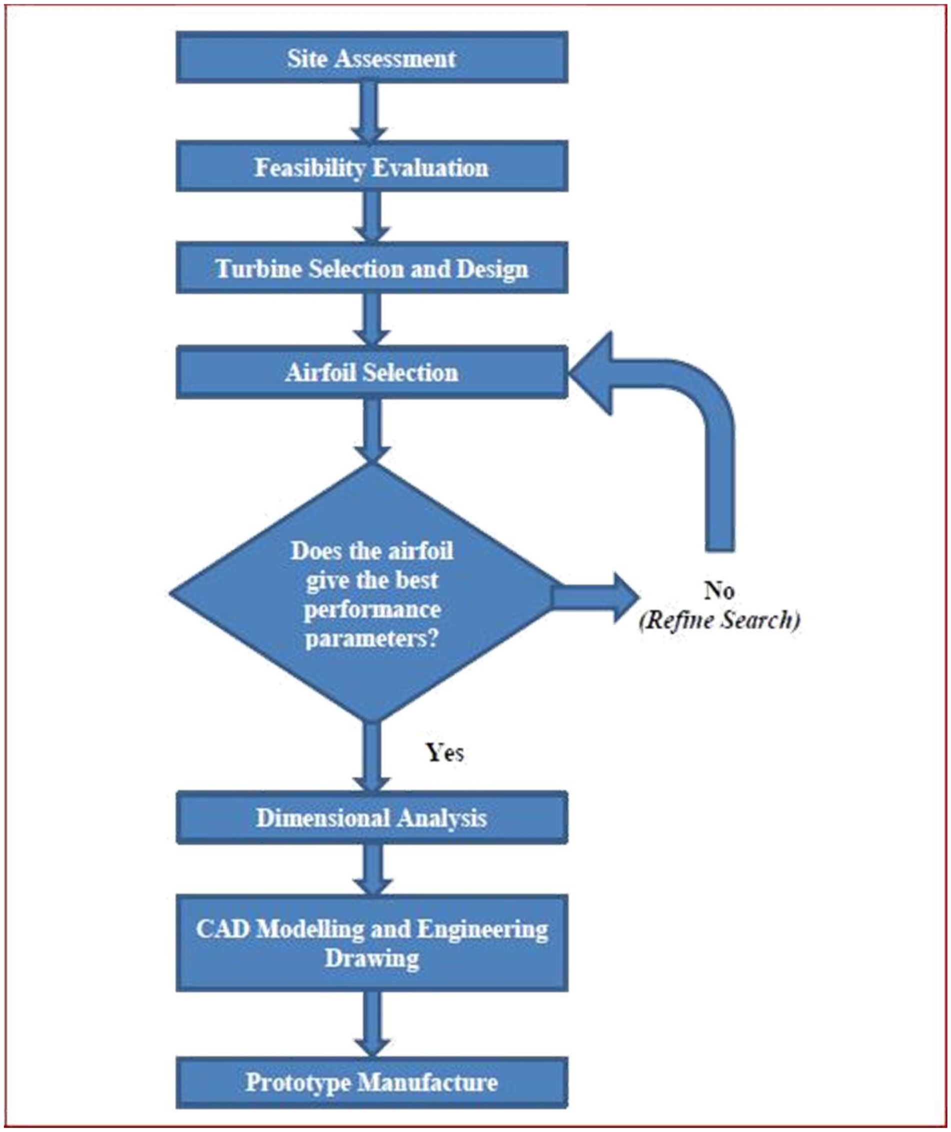


Figure-1

The main objective of this project is to find a solution to the problem: designing, fabricating and testing a reaction turbine with low head and high flow rate.

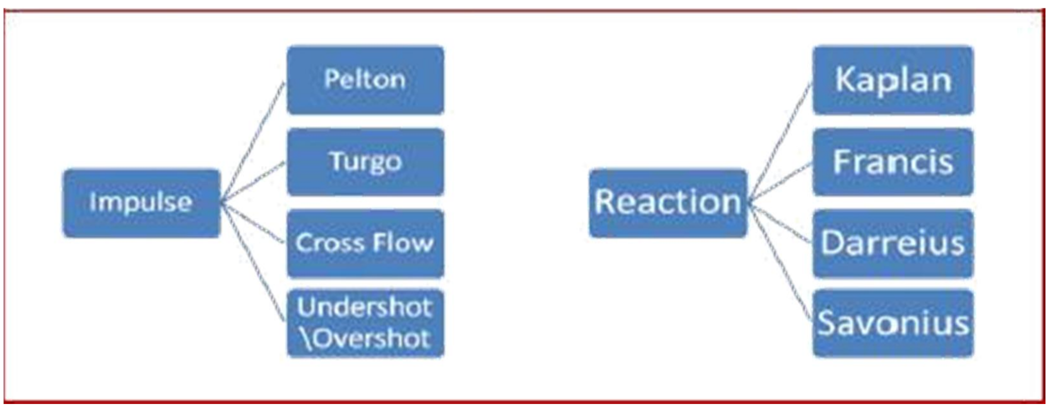
The literature review conducted in order to follow and complete this project methodology has been discussed in the next section.

LITERATURE REVIEW

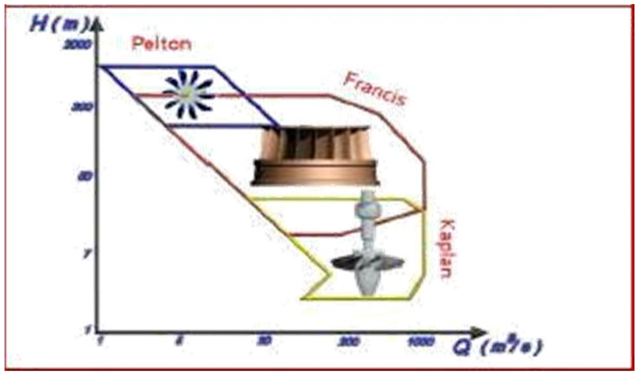
In the sub-field of turbine of rotating turbo machinery, various classifications exist to characterize the different types of turbines that produce shaft power from the movement of fluids. One primary classification is upon the basis of primary-moving force – the impulse force or the reaction force.

Hence, there are two types of turbines,

1. Impulse turbines
2. Reaction turbines



Impulse turbines are efficient for very high heads and low flow rate, whereas reaction turbines are efficient under low head and high flow rates. Specific speed is perimeter used to select which turbine is suitable under any specific conditions.



The figure shown above represents the Francis Turbine suite to average head and average flow rate.

$$C_H = \frac{gh_a}{w^2D^2} \qquad C_Q = \frac{Q}{wD^3} \qquad C_P = \frac{W_{Shaft}}{\rho w^3 D^5}$$

Turbine Type	Specific Speed Range
Impulse Turbine	< 0.3
Francis Turbine	0.3 – 1.5
Kaplan Turbine	>1.5

Table-1

Specific speed of turbine is at which turbine will run when it produce unit power under unit head.

These are all unit less numbers used for turbine scaling. Turbines with similar values for theses constants will behave similarly.

CH is head constant, CQis flow constant and CP is power constant.

Specific speed= $(CP)^{1/2} / (CH)^{5/4}$

g = gravitational acceleration

h = head

w = angular velocity

D = diameter

Q = volume flow rate

In our case, an assessment on an Average-Head and Average-Flow rate Turbine, called the Francis Turbine will be carried out. Francis Turbine is best suited for our conditions (as demonstrated in case study in following pages).

The Francis turbine is a type of water turbine that was developed by James Francis in Lowell, Massachusetts. It is an inward-flow reaction turbine that combines radial and axial flow concepts.

Francis turbines are the most common water turbine in use today. The electric generator which most often use this type of turbine, have a power output which generally ranges just a few kilowatts up to 800 MW, though mini-hydro installations may be lower. The speed range of the turbine is from 83 to 1000 rpm. Wicket gates around the outside of the turbine's rotating runner control the rate of water flow through the turbine for different power production rates. Francis turbines are almost always mounted with the shaft vertical to keep water away from the attached generator and to facilitate installation and maintenance access to it and the turbine.

CASE STUDY

A team of engineers from the School of Mechanical and Manufacturing Engineering at the National University of Sciences and Technology, Islamabad assessed the feasibility of developing hydro-energy projects at the Kunhar River Basin within the Kaghan Valley in the Northern Areas of Pakistan. The study included an opportunity assessment, technical research and an investigation into legislative, planning and environmental constraints.

The team also provided the client with advice on technology options and scale, based upon their source feasibility.

Certain sites were established on Kunhar river basin with steam with approximate flow rate of .5m^3 per second and available head of 4 meters. Analysis by specific suggested Francis turbines to be most suitable turbine type.

Figure-2

Site Data:

Path	Penstock Length (ft.)	Head (ft.)
A	200	4
B	300	6
C	400	10
D	550	10

TURBINE DESIGN (FRANCIS TURBINE)

Turbine Selection

Impulse turbines work on high head, low flow rate, reaction turbines work on low head high flow rate. Specific speed is parameter used to select suitable turbine type.

Turbine Type	Specific Speed Range
Impulse Turbine	< 0.3
Francis Turbine	– 1.5
Kaplan Turbine	>1.5

Table-2

Specific speed of turbine is at which turbine will run when it produce unit power under unit head.

These are all unit less numbers used for turbine scaling. Turbines with similar values for theses constants will behave similarly.

$$C_H = \frac{gh_a}{w^2 D^2}$$

$$C_Q = \frac{Q}{wD^3}$$

$$C_P = \frac{W_{Shaft}}{\rho w^3 D^5}$$

$$C_P = \frac{\rho Q g h_a}{W_{Shaft}}$$

CH is head constant, CQ is flow constant and CP is power constant.

Specific speed= $(CP)^{1/2} / (CH)^{5/4}$

Turbine Design

Parameters	NAUTILUS 8" CMC Type	Book Example	Custom 1	Custom 2
Head (effective)	1.200	50.00	2.00	1.800
Euler Head	1.020	45.00	1.700	1.530
Flowrate (l/min)	1988.00	56940.00	1500.00	1200.00
Flowrate(m^3/s)	0.033	0.949	0.025	0.020
Flowrate(l/s)	33.133	949.00	25.00	20.00
Power	265.231	397989.248	333.540	255.158
Rpm N	300.00	800.00	240.00	300.00
Rotation in rad/s	31.416	83.779	25.133	3.416
Specific speed	0.742	0.724	0.352	0.438
General Specific speed	123.015	120.036	58.277	72.683

Table-3

In table shown above turbine 'Custom 2' shows design parameters for turbine. Design is finalized and we are making a Francis turbine prototype. 'Nautilus 8" CMC type' in column 2 is commercial turbine. In the table above you can also see comparison between our design parameters and of other commercial turbines.

Assumed mechanical and hydraulic efficiencies ate 85%, which give us overall efficiency (of turbine) of 72%. Overall efficiency do not account for external losses which include, losses in pipe flows, and losses as result of kinetic energy at exit.
Effective head drop across turbine will be 1.8m (after eliminating external losses). We have to design turbine at constraint of very low flow rate, so turbine will only

be able to produce limited performance. Flow rate used will be 1200 liters/min, and specific speed will fall around .438 if turbine is set to rotate at 300 rpm.

Other design parameters include:

Speed ratio Ku = u1 / (2gH) ½

Flow ratio Kf =Cf1 / (2gH) $^{1/2}$

n (ratio of width of runner at inlet divided by diameter of inlet) = B1 / D1

Design parameter	Approximate Value
Ku	.6 to .7
Kf	.15
n	.1 to .45

Table-4

D1 and B1 in custom 2 are 24.6 cm and 3.5 cm.

Pelton wheel is used for high heads. But there are many places where available head may not be that high as required for Pelton turbine. In that case, as mentioned earlier, we can still generate reasonable waterpower running a machine with high discharge. But this is not that simple as it seems to be. Lower H means lower u (tangential velocity of runner) for same optimum value 0.47 of Ku (for Pelton wheel) and therefore lower runner diameter D, since rpm of a turbine is controlled by the generator. This in turn will reduce area of flow as it is equal to ΠDB. Thus for a machine designed for Ku = 0.47, both diameter and width of the wheel will be less and hence it will produce lower power, which we do not intend to. So a solution lies in increasing Ku and Kf.

Since the available head is reduced by the height of the wheel from tail race, positioning the Pelton wheel above tail race is a problem. A solution to put the turbine under water is not feasible because of maintenance reason. Therefore, solution was thought in the form of a closed turbine in which fluid expands on the runner blades inside a closed casing so that pressure at exit is lower than atmospheric pressure. Water is then taken to tail race by a diverging tube, called draft tube. This gives flexibility to place turbine anywhere above tailrace. Water, supplied to scroll casing by penstock from head race, enters fixed guide vanes placed round the runner. Water comes out from guide vane in a direction along tangent to runner blade at entry so that fluid enters smoothly without any shock at designed operating conditions. Francis turbine shaft is vertical and therefore plane of runner rotation is horizontal; water comes out from runner is radial direction and falls to draft tube by gravity.

Francis developed three types of runners with increasing Ku, Kf. blade angles in three cases are >90degree (slow runner), =90 degree (medium runner) and <90 degree (fast runner). High speed runner suits low head condition whereas slow runner fits high head situation.

Francis Turbine is a reaction turbine as the area of flow decreases along the runner vanes which accelerated the flow. It provides a wide choice to designer since blade inlet angle can take any value. Working proportion of Francis turbine is:

n = ratio of width B1 of runner at its inlet to inlet diameter D1= B1/D1 = 0.10 to 0.45

Stepwise design of Francis turbine to develop power (P) from available head (H) and flow rate (Q) at rpm (N) is given below:

In our prototype design H = 1.8 meters, rpm (N) was 300.

Step 1: Assume suitable value of hydraulic and overall efficiency, n, Ku, Kf, and vane thickness coefficient Kt. Kt accounts for the area occupied by the thickness of blade; it is around 10%. Thus area of flow is reduced to 90% to 95% of theoretical area. More is the number of guide veins; more is the reduction in area.
In our prototype assumed values are: hydraulic efficiency = 85 %, overall efficiency = 72 %, n = .140, Ku = .648, Kf = .140 and Kt = .10.

Step 2: Determine power using equation:

$$P = \rho g H Q n$$

Where,

P = Power (Watt)
ρ = Density of Water (1000 kg/m^3)
g = Acceleration Due To Gravity (9.81 m/s^2)
H = Gross Head (Meter)
Q = Flowrate (m^3/s)
n = Efficiency of the System

.

Step 3: Using mass conservation principle, wheel diameter at inlet is determined.

$Q = (K_t * D_1 * B_1) * C_{f1}$

$C_{f1} = K_{f1} (2gH)^{.5}$

$D_1 = [Q / \{K_{f1} * K_t * \quad * n * (2gH)^{.5}\}]^{1/2}$

Once D_1 is known B_1 can be obtained.

In our prototype D_1 = 24.6 cm and B_1 = 3.5 cm.

Step 4: Now u1can be obtained from equation: u1= D1N/60.

U_1 in our turbine is 3.872 m/s

Step 5: Assuming radial flow at exit, i.e., C_{w2} =0 (simplification), C_{w1} can be obtained from the Euler turbine equation. Inlet triangle can be drawn now and angles β_1 (blade angle at inlet) and α_1 (flow angle at inlet) can be obtained using trigonometric relations.

In our prototype angle β_1 (blade angle at inlet) = 90 degree and α_1 (flow angle at inlet is approximately 12 degree. Runner inlet condition is set so to make it medium runner.

The picture below shows velocity profile at inlet. We aim to get B1 equal to 90 degrees, by making whirl velocity CW1 equal to blade velocity u1. This will make blade manufacturing easier. Angle a1 will be between 22 degrees.

At outlet whirl velocity will be equal to zero.

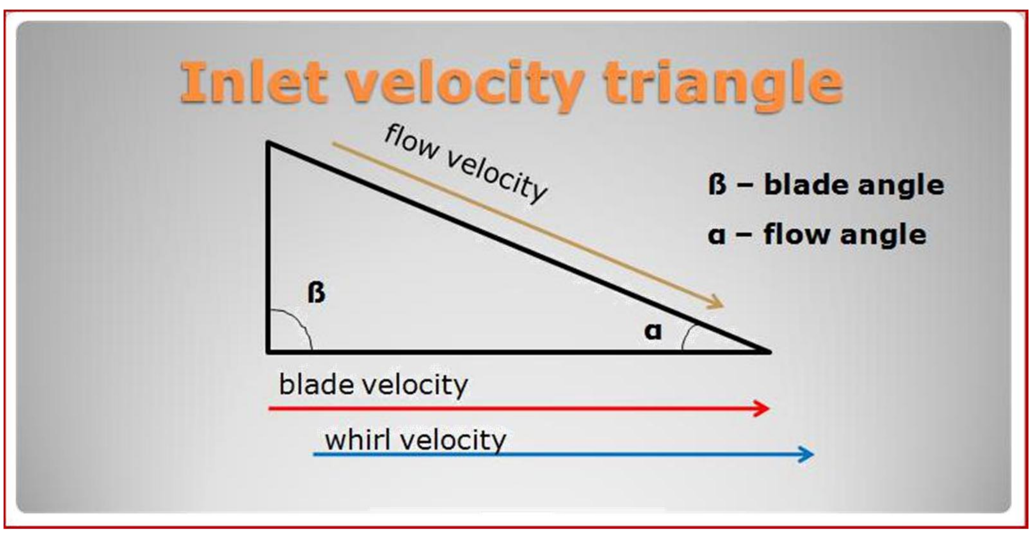


Figure-3

Step 6: Normally D2is D1/2 and flow is assumed to remain constant. Continuity equation gives B2=B1.

Step 7: Draw outlet velocity triangle and determine angle β2.
In our prototype β2 is approximately 25 º.
At outlet whirl velocity will be equal to zero.

Step 8: Ensure that design leads to a cavitations free turbine that requires condition for cavitations factor or NPSH must be satisfied. It may be mentioned that pressure at turbine exit is below atmosphere. Therefore, if it goes too low then water vapor may form which move downstream in a draft tube in which the pressure increases. Therefore, cavitations will occur in a draft tube. Pressure at the turbine exit can be obtained by considering draft tube as diverging pipe.

In prototype draft tube will expand at angle of 10 degree and will be kept as short as possible.

Turbine casing was designed in a way that area drops uniformly around 360 º.

Blade design

An airfoil is the shape of a wing or blade (of a propeller, rotor, or turbine) or sail as seen in cross-section.

An airfoil-shaped body moved through a fluid produces an aero dynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. Subsonic airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with a symmetric curvature of upper and lower surfaces. Foils of similar function designed with water as the working fluid are called hydro foils.

The lift on an airfoil is primarily the result of its angle of attack and shape. When oriented at a suitable angle, the airfoil deflects the oncoming air, resulting in a force on the airfoil in the direction opposite to the deflection. This force is known as aerodynamic force and can be resolved into two components: lift and drag. Most foil shapes require a positive angle of attack to generate lift, but cambered airfoils can generate lift at zero angle of attack. This "turning" of the air in the vicinity of the airfoil creates curved streamlines, resulting in lower pressure on one side and higher pressure on the other.

This pressure difference is accompanied by a velocity difference, via Bernoulli's principle, so the resulting flow field about the airfoil has a higher average velocity on the upper surface than on the lower surface. The lift force can be related directly to the average top/bottom velocity difference without computing the pressure by using the concept of circulation and the Kutta-Joukowski theorem.

An analysis was conducted on different NACA-based airfoil sections in order to arrive at the best airfoil section that could yield the best possible efficiency for the turbine based on site conditions.

A brief summary of NACA airfoil series is listed in the table below.

Family	Advantages	Disadvantages	Applications
4-Digit	1. Good stall characteristics 2. Small center of pressure movement across large speed range 3. Roughness has little effect	1. Low maximum lift coefficient 2. Relatively high drag 3. High pitching moment	1. General aviation 2. Horizontal tails ***Symmetrical:*** 3. Supersonic jets 4. Helicopter blades 5. Shrouds 6. Missile/rocket fins
5-Digit	1. Higher maximum lift coefficient 2. Low pitching moment 3. Roughness has little effect	1. Poor stall behavior 2. Relatively high drag	1. General aviation 2. Piston-powered bombers, transports 3. Commuters 4. Business jets
16-Series	1. Avoids low pressure peaks 2. Low drag at high speed	1. Relatively low lift	1. Aircraft propellers 2. Ship propellers
6-Series	1. High maximum lift coefficient 2. Very low drag over a small range of operating conditions 3. Optimized for high speed	1. High drag outside of the optimum range of operating conditions 2. High pitching moment 3. Poor stall behavior 4. Very susceptible to roughness	1. Piston-powered fighters 2. Business jets 3. Jet trainers 4. Supersonic jets
7-Series	1. Very low drag over a small range of operating conditions 2. Low pitching moment	1. Reduced maximum lift coefficient 2. High drag outside of the optimum range of operating conditions 3. Poor stall behavior	Seldom used

Table-5

It was apparent that the NACA 16-Series Set of airfoils was the most suited to propeller blade applications, and was the basis of further study.

Blade was designed with theoretical analysis with proper airfoil and in accordance with velocity triangles. Images of runner and blade are shown below.

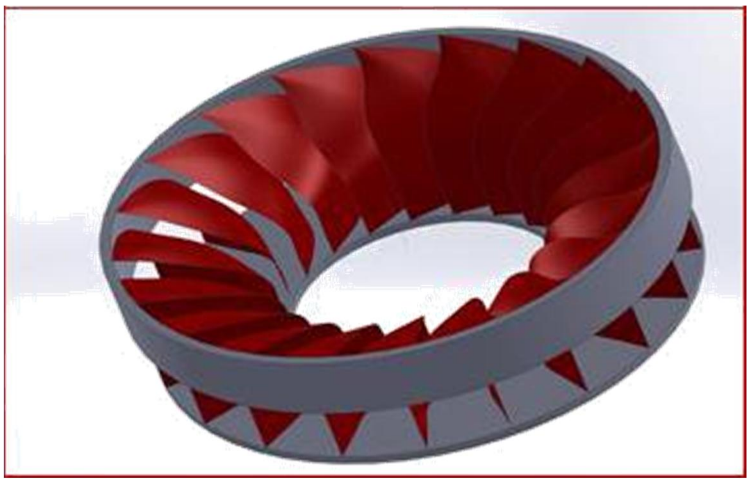


Figure- 4 Blade profile

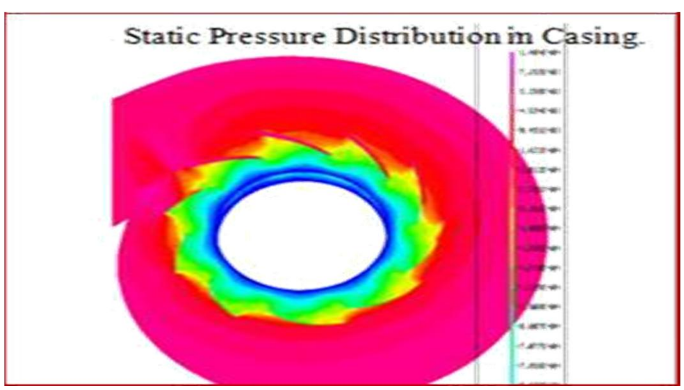


Figure-5 Pressure distribution

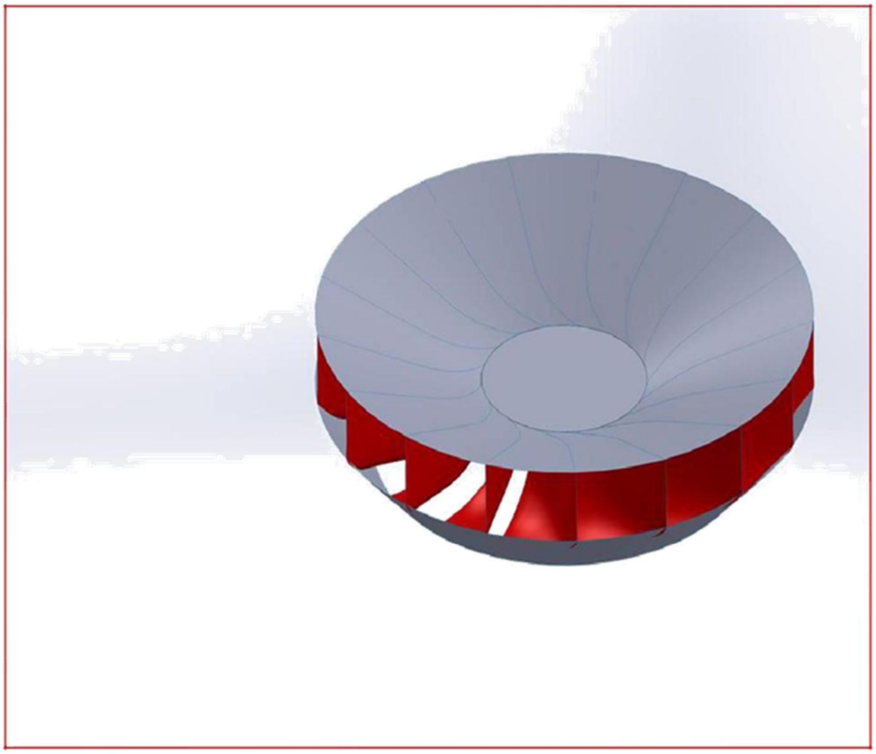


Figure-6 Blade profile

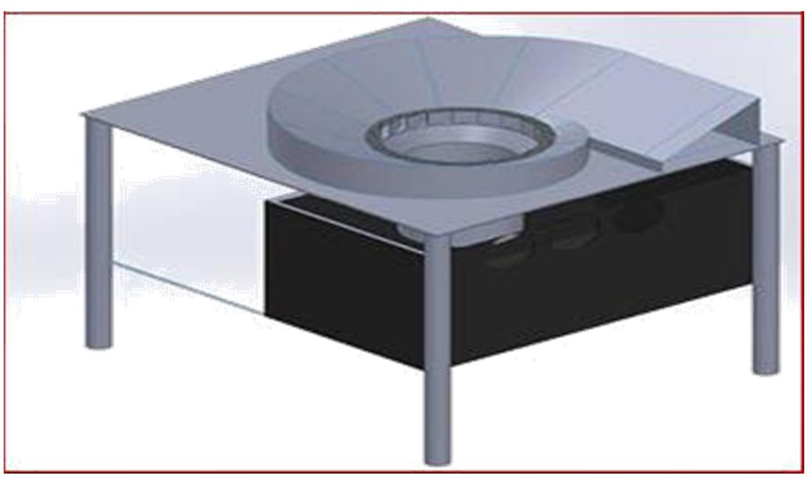


Figure-7 Test bed design

DYNAMOMETER

Dynamometer is a device which is used to measure the torque and power produced by the engine, motor or any type of prime mover. For the test rig of our project we will need a dynamometer to measure the power of the francis turbine.

There are three basic types of dynamometers:

1. Absorption or passive dynamometer: Dynamometer designed to be driven
2. Motoring or driving dynamometer: Dynamometer designed to drive
3. Active or universal dynamometer: Dynamometer designed to drive or be driven

For our francis turbine we will be driving our dynamometer by the turbine shaft so absorption dynamometer will be used. There are many types of dynamometer so we choose the type which was most suitable to our need. We did assessment of technical, performance, schedule, economic and resource factors for each type and outclass the most suitable type. Each type's pros and cons are discussed below.

Mechanical Absorption Type:

In this type mechanical brakes are applied to transfer the shaft energy and then it is measured using the load cells or strain gauges. It is the simplest type of dynamometer which requires different setup for every need. We studied each and every setup like prony-brake dyno, rope brake dyno, band brake dyno, torsion dyno. There are many frictional losses in them also the major problem is that this setup results in the loss of the turbine energy while the power is being measured.

Transmission Absorption Type:

In this type the power is absorbed but is not lost but is stored in the belt until the power is measured with the help of the load cells. It has different configurations like Belt transmission and epicyclical gear train. Tatham transmission and Mccall transmission dynamometer are the simplest types. The principle used in this type of dyno is that when belt transmits power there is a difference in tension between the two sides of the belt and a relation is derived between the absorbed force and the tension of the belts through which torque and power and then measured. There are huge amount of frictional losses in the pulleys we discarded this type.

Electric Absorption Type:

In this type electric brakes are used to absorb the shaft power and then load cells are used to calculate the power. It uses the eddy current and lens's principle. The most common type of electric absorption is Eddy Current dynamometer. It is the most efficient dynamometer but its construction is the most expensive and complicated. They use the electric supply to charge the electromagnetic coils. Input shaft spins the metallic rotor inside the resulting magnetic field the eddy currents produced charge the electromagnetic coils which try to rotate and the strain gauge is attached to it which is then calibrated to find the torque.

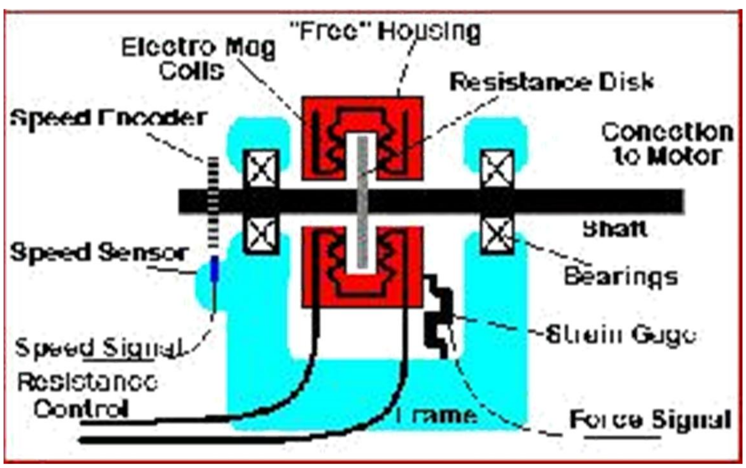


Figure-8

We discarded this type as its construction is very expensive also it is used for high rpm and voltage while in our project we have approximated dyno output range to be 100-300 watts.

Water Absorption Type:

The water braking system is largely based upon centrifugal pumping laws. The turbine shaft will power the pump impeller and the power of the turbine will dictate the pumping ability and thus output of the system. Varying the inlet water flow through a valve can control the amount of load placed on the engine. Load cells are attached to the stator i.e., housing to calculate the power.

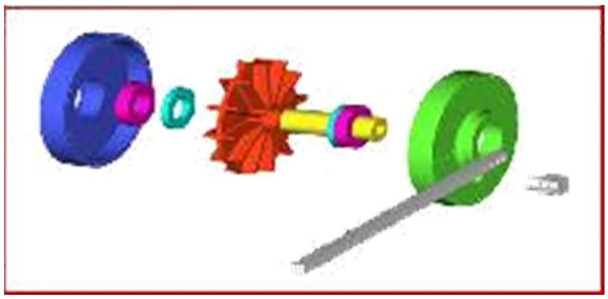


Figure-9

AC Electric generator Type:

In this type alternator or generator is used to absorb the shaft power and then the electric current produced by the alternator will vary according to the load on the turbine. The output electric current is then calibrated with the help of portable dynamometer to measure the power of the turbine. This is a simple type, its manufacturing cost is also very low plus it is efficient and according to our use because we will be using dyno to charge batteries and also for measuring the torque. It is suitable for our range. So this type is outclassed and we will be using this type of dyno for our test rig.

The function of the alternator is explained on the next page

ALTERNATOR

Introduction

An alternator is a synchronous AC electric generator with DC diode rectification and pulse width modulation voltage control. Its power producing parts are rotor, stator, diode rectifier and voltage regulator.

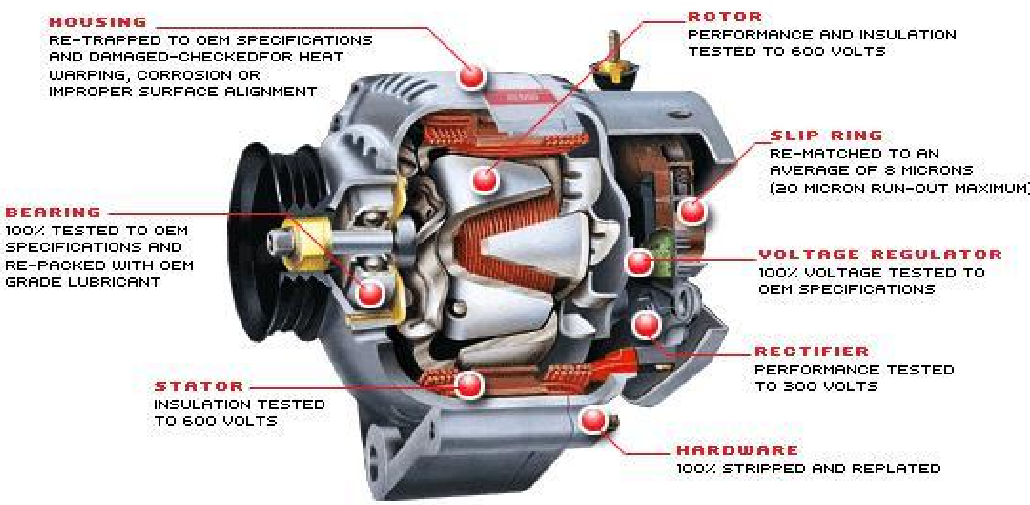


Figure-10

Rotor

The rotor is main part and heart of an alternator. Electrical power production is only possible because it provides a rotating magnetic field. It consists of an iron core, field coil winding, two iron segments that are claw shaped in appearance, hence the claw pole alternator and a shaft. The field coil windings usually consist of 300-500 tightly wrapped coil of copper wire which is round and insulated.

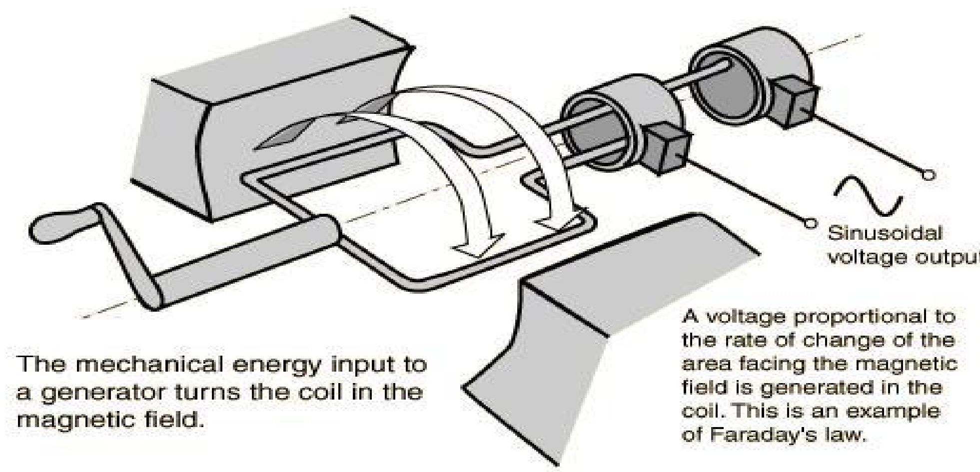


Figure-11

Faraday's Law of electromagnetic induction states that the emf induced in the coil is given by the rate of change of flux change of the coil

Stator

The stator is the stationary part of the alternator where the mechanical to electrical energy conversion takes place. It has an iron core, which completes the magnetic circuit created by the rotor, and copper windings.

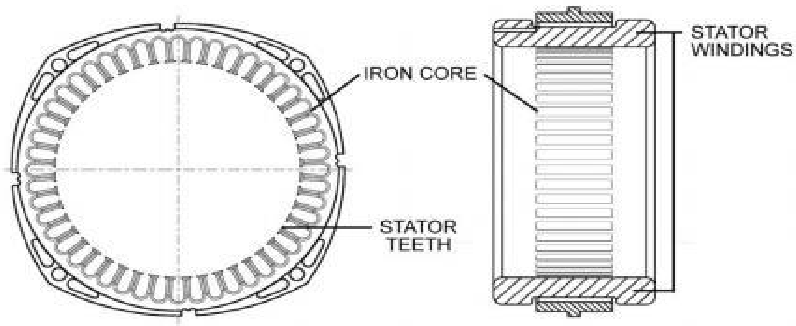


Figure-12

These stator teeth provide an electromagnetic path that connects the North and South poles of the rotor through the stator. AC magnetic flux will be produced in the stationary stator once the rotor rotates. This varying flux will induce a voltage into the stator wire as the Faraday's law states that

$$e = -N_c(d\Phi/dt)$$

where e = Voltage induced in a conductor.

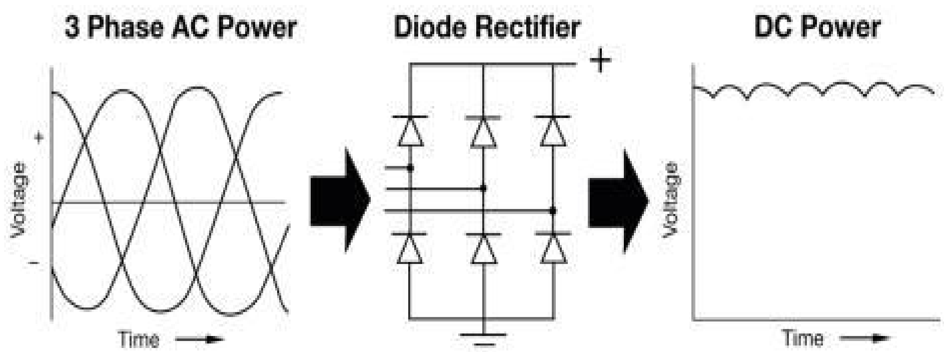
N_c = Number of conductors in series.

$d\Phi/dt$ = Time rate of change of flux.

The relationship stated above describes the voltage induced in each length of stator wire. To increase Nc, the number of conductors in series (stator wire) will be coiled multiple times through each slot. This increases the voltage induced.

Rectifier

The diode rectifier takes the AC electrical power coming from the stator and converts it to DC electrical power. The rectifier has 6 diodes which behave like a check valve allowing the current to flow in only one direction. Using two diodes stator per phase, it converts or rectifies AC power into DC power with a corresponding voltage ripple.



Voltage Regulator

The purpose of a voltage regulator is to sense the operating voltage and sense the output of the alternator accordingly. The regulator compares the external voltage signal to its internal set point. If the voltage is too high it responds to decreasing the output of an alternator and vice versa.

The overall circuit of an alternator is

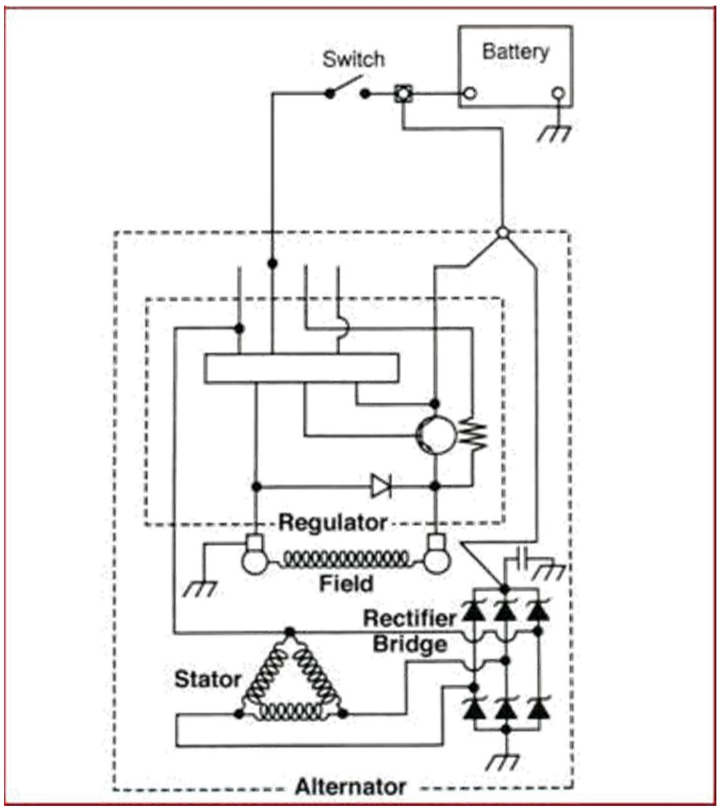


Figure-13

Summary

The magnetic field is provided by the rotor which induces a voltage in the stator. The stator, due to the induced magnetic field, rotates with the same speed or synchronously with the rotor field. The diode rectifier is connected to the stator windings which convert AC power into DC power. The voltage regulator changes the output of the alternator by monitoring the system voltage

Losses in an alternator

The following table summarizes the various power losses:

Electrical	
Stator winding loss	$P_{stator} = (i)^2 (R_{stator})$
Rotor winding loss	$P_{field} = (i)^2 (R_{field})$
Rectifier diode voltage drop loss	$P_{diode} = (V_d) (i_{diode})$
Regulator output device drop loss	$P_{regulator} = (V_d) (i_{regulator})$
Brush drop	$P_{brushes} = (i_{field})^2 (R_{brush})$
Magnetic	
Eddy current	$P_{eddy} = (k) (T)^2 (RPM)^2 (B)^2$
Hysteresis	$P_{hysteresis} = (k) (RPM) (B)^2$
Stray	$P_{stray} = (0.01) (P_{total\ loss})$
Mechanical	
Bearing friction	$P_{bearing} = (k) (RPM)$
Windage	$P_{windage} = (k) (RPM)^3$

Figure-14

FABRICATION

The material used for fabrication is galvanized mild steel which was spray painted to avoid any corrosion during the one week period of test run of the turbine.

Carbon steel is steel in which the main interstitial alloying constituent is carbon in the range of 0.12–2.0%. The American Iron and Steel Institute (AISI) define that:

Steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.

The term "carbon steel" may also be used in reference to steel which is not stainless steel; in this use carbon steel may include alloy steels.

The workshop operations used to do all the fabrication are,

1. Bending
2. Plasma Cutting
3. Shearing
4. Welding (Shield metal arc welding)
5. Bench fitting
6. Punching
7. Filing
8. Drilling
9. Fitting

The operations mentioned above were used to fabricate all the parts. Fabricating the final product was one of the most difficult jobs because of lack of resources available at SMME. The final product was made in a time period of two weeks.

Figure-15 Fabricated Turbine test bed

Figure-16 Fabricated Blade profile

Figure-17 Fabricated blade profile.

Figure-18 Fabricated guide vanes

Figure-19 Spiral casing

Figure-20 Test bed-Spray painted

The parts shown on the above diagrams were successfully fabricated. Thus, we went on to the Testing of the turbine.

TESTING

For testing, the site chosen was at the back of MRC. The equipment and additional things needed for testing was brought separate from the market which included,

1. PVC pipes
2. Water Tanks (500 liters)
3. Pipe plugs
4. Ball valves
5. Elbow joints
6. Silicone sealant
7. Silver spray paint
8. Bricks
9. 3m high table
10. Pipes
11. Multi-meter
12. Resistors
13. Electric wires
14. Hacksaw
15. Magic Epoxy
16. DC motor (reversed)

SEALING

Sealants, despite not having great strength, convey a number of properties. They seal top structures to the substrate, and are particularly effective in waterproofing processes by keeping moisture out (or in) the components in which they are used. They can provide thermal and acoustical insulation, and may serve as fire barriers. They may have electrical properties, as well. Sealants can also be used for simple smoothing or filling. They are often called upon to perform several of these functions at once.

A corking sealant has three basic functions: It fills a gap between two or more substrates; it forms a barrier through the physical properties of the sealant itself and by adhesion to the substrate; and, it maintains sealing properties for the expected lifetime, service conditions, and environments. The sealant performs these functions by way of correct formulation to achieve specific application and performance properties. Other than adhesives, however, there are few functional alternatives to the sealing process. Soldering or welding can perhaps be used as alternatives in certain instances, depending on the substrates and the relative movement that the substrates will see in service. However, the simplicity and reliability offered by organic elastomers usually make them the clear choice for performing these functions.

Figure-21 Sealing using silicone sealant.

The head designed to test the turbine was 1.8 m. To keep the water head of the tank constant, another tank was used which had the same volume flow rate, as of the tank used as an inlet to the turbine.

Figure-22 Constant water head maintained

The diagram shown above represents the over-all setup of the testing of our Francis turbine.

Figure-23 Turbine testing

The tank at the top was used to keep the water head constant. Its operation worked in a way that the as soon as the plug of the tank below was opened, the valves of tank at the top were opened too. This maintained high flow rate of the water. The draft tube has to be fully dipped in the water which helps to maintain a good flow rate throughout its operation. The testing of the turbine was done a couple of time and the recorded results were the three best tries. Multi meter was connected at the end of the DC motor, which operated in reverse. A simple circuit consisting of resistors and electric wires and multi meter was used to measure the voltage produced to get the power output.

Some of the losses are mentioned below.

The following table summarizes the various power losses:

Electrical	
Stator winding loss	$P_{stator} = (i)^2 (R_{stator})$
Rotor winding loss	$P_{field} = (i)^2 (R_{field})$
Rectifier diode voltage drop loss	$P_{diode} = (V_d) (i_{diode})$
Regulator output device drop loss	$P_{regulator} = (V_d) (i_{regulator})$
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Magnetic	
Eddy current	$P_{eddy} = (k) (T)^2 (RPM)^2 (B)^2$
Hysteresis	$P_{hysteresis} = (k) (RPM) (B)^2$
Stray	$P_{stray} = (0.01) (P_{total\ loss})$
Mechanical	
Bearing friction	$P_{bearing} = (k) (RPM)$
Windage	$P_{windage} = (k) (RPM)^3$

Table-6 Power Losses

These losses dissipated more energy than expected and can be easily minimized if a dyno was used rather than reversing a DC motor. The turbine's testing was carried out in a controlled environment

RESULTS

Voltage/ V	Resistance/ Ohm	Generation loss /W	Power/ W
30.3	10	70	157.1
25.6	7.5	70	159.1
27.5	7.5	70	170.1

Table-7

*Power calculated using P=V^2/R

We were successfully able to produce 170.1, 159.1, 157.1 W of power on our three consecutive tests.

*Power losses due to back emf produced = 70 W

RECOMMENDATIONS

With respect to the Hydro Power Potential in Pakistan, a major portion of the overall capacity is unused, and small Micro-Hydro Projects like these in addition to larger Mega Projects can help alleviate the energy crisis of Pakistan and also pave the way for future research in the field of turbine design.

Turbine efficiency greatly depends upon the design of its blades. It is recommended that in addition to the airfoils already assessed, other NACA and non-NACA Series airfoils should also be checked for the best possible operating parameters like Lift-Drag Ratios and Stall Characteristics, as this can help improve the efficiency of the turbine design. Instrumentation is an important aspect of all experimental apparatus, and was one of the constraints encountered in the course of this project. Instrumentation that can help with the measurement of various quantities such as the flow-rate, pressure drop, turbine rotational speed (RPM), and especially torque produced can greatly help improve the accuracy of the results of the experimentation. Instrumentation can also be done in order to measure the amount of cavitation that occurs in the turbine as a result of pressure drops during operation. This can help research new materials and composite materials that can potentially drastically increase the life and reliability of the turbine. The guide-vanes/stay-vanes section of the Francis Turbine was briefly assessed during the course of his project. Guide Vane design theory is rather expansive in nature, and needs to be considered in detail in order to obtain the best efficiency of operation during variable flow-rates. Lastly, turbines in general are most suited for operation at the exact location for which they were designed, otherwise their efficiencies can drop. In order to mass produce turbines in this context, they need to be featured with variable pitch-angle blades, and also variable guide-vanes in a double-regulated configuration, so that they can be adjusted for best performances and efficiencies on different sites.

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