MODIFICATION IN CROSS FLOW TURBINE FOR EFFICIENCY IMPROVEMENT

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
ALTERNATE HYDRO ENERGY SYSTEMS

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation, entitled, "**MODIFICATION IN CROSS FLOW TURBINE FOR EFFICIENCY IMPROVEMENT**", in partial fulfillment of the requirement for the award of the degree of **Masters of Technology** in "**Alternate Hydro Energy Systems**", submitted in Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period from July 2009 to June 2010 under the supervision of **Dr. R.P.Saini**, Associate Professor and **Dr. S.K.Singal,S.S.O.**, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, India.

I have not submitted the matter embodied in this dissertation for award of any other degree.

Dated: June, 30, 2010
Place: Roorkee

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

The popularity of the turbines under micro hydro lies in the fact that they are less costly and can be fabricated locally. There are various types of turbines that can be used in micro hydro. Cross-Flow turbine has been considered techno-economically viable for such sites.

A cross flow type runner has a drum shape consisting of two parallel discs connected together by a series of curved vanes or blades. The water from the nozzles strikes the vanes and convert 2/3rd part of the potential into the mechanical power. The water that comes out from the blade, strikes the diametrically opposite vane and the remaining conversion of 1/3rd part takes place. Cross flow type runner can be fabricated locally, which results in the poor efficiency. The vanes can be made even from the pipes cut along the length. Also this kind of runner is suitable for low discharge and high head conditions, which is a common case in the hills.

The problem with the fabrication of cross flow turbine runner at the local level is that its efficiency decreases due to lack of proper design and fabrication. The low efficiency is the basic inspiration to improve the existing design of cross flow runner.

There is a scope of efficiency improvement in cross flow turbine by guiding the water jet from first stage to second stage with the help of a guide tube.

This study presents the design modifications in cross flow turbine. The runner was designed and fabricated by providing the guide tube. The guide tube is designed and fitted with the runner. The cross flow turbine has been tested before providing guide tube and after fitting guide tube.

It has been observed that the efficiency of cross flow turbine is increased by introducing guide tube to guide the crossing flow towards the second stage of the runner. This study intends to design the cross flow turbine runner with guide tube to improve the efficiency. The modified runner can be used for further study in order to improve the performance of a cross flow runner considering other design parameters such as providing draft tube.

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NOMENCLATURE

kW = Kilowatt

MW = Megawatt

P = Power

ρ = Density of water

Q = Discharge

H = Net Head

η_0 = overall efficiency of the turbine

R_1 = Outer Radius of the Runner

R_2 = Inner Radius of the Runner

β_1 = Outer Blade Angle

β_2 = Inner Blade Angle

r_b = Curvature Radius of the Blade

r_p = Pitch Circle Radius

δ = Segment Angle of the Blade

ϕ = Angle in radius between two points on the Spiral and the origin of the Spiral

e = Natural Logarithm

K = Cotangent of the angle between the tangent to the logarithmically Spiral

b = Inlet Width

ϕ'' = Admission Arc Angle

α = Angle of Absolute Velocity

L = Admission Arc Length

p = Static pressure

V = Velocity

CHAPTER-1

INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL

Energy is vital for sustaining on earth. Energy was, is and will remain the basic foundation, which determines the stability of economic development of any nation. It is needed to increase quality of life. Supply of energy for both biotic and a-biotic life support system is only possible by exploiting natural resources. The energy problem is, thus synonymous to ecological and economical problems. The gap between supply and demand of energy is continuously increasing despite of huge outlay for energy sector since independence. The total installed generating capacity of electricity in India is 1, 59,648.41 MW in May 2010 [1], 70% of which is supplied through fossil fuel (coal), about 25% through hydro where as the nuclear power contributes a little less than 5% of the total power. The nuclear energy share in the world is 16%. The demand for electrical energy in India is rapidly increasing due to industrial and population growth, outstripping the available generation.Fig.1.1 shows the sector wise power consumption in India.

. Among installed capacity, at present the largest share (>60%) was because of thermal electricity. There is 120% increase in annual oil production at 50 million tons, about 250% increase in annual coal production at 600 million tones and doubling of natural gas production at 100 million cubic meters per day for the year 2012 [2]. This extraordinary growth in demand will place great stress on the financial, managerial and physical resources of the country, creating capital and energy shortages as well as environmental problems.

World energy demand has been increasing exponentially. It has been estimated that the world population will reach 8 billion by 2020[2]. On other hand, the conventional energy resources are limited on the earth and also its use affects the environment. there is an urgent need to explore the wide use of alternative energies technologies. Accepting this challenge, engineers, scientists and energy economists are putting every effort to ensure that the energy need will be provided distributed, used and conserved in a sustainable manner locally and globally.

Since the post independence era the power sector in India has registered significant progress after the process of planned development of the economy began in 1950. Hydropower and coal based thermal power have been the main sources of generating electricity. Nuclear power development is at slower pace, which was introduced, in late sixties. The concept of operating power systems on a regional basis crossing the political boundaries of states was introduced in the early sixties. In spite of the overall development that has taken place, the power supply industry has been under constant pressure to bridge the gap between supply and demand. The demand for power in the country has been growing at the rate of 8% per year.

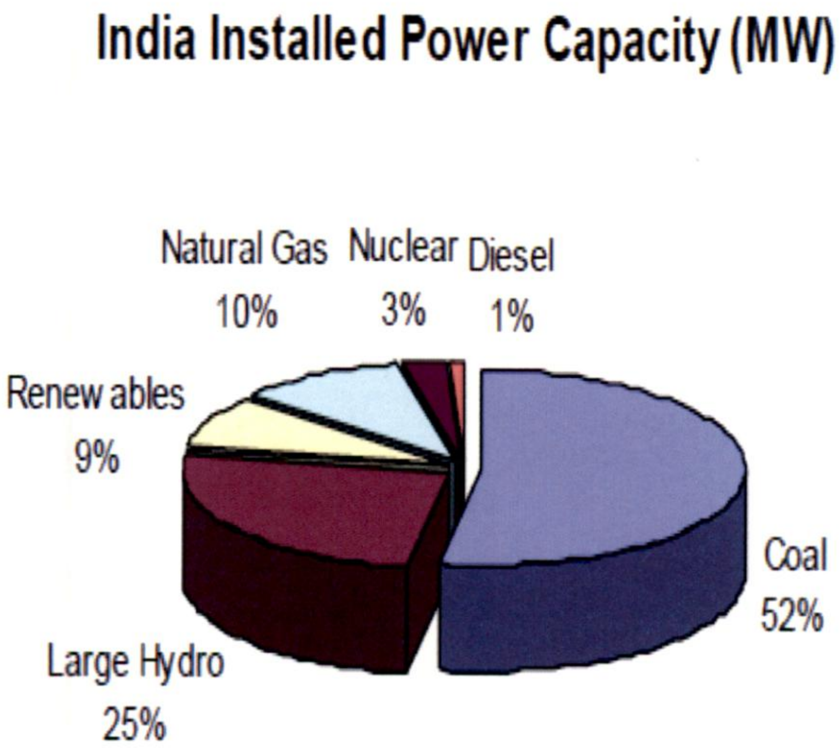


Fig.1.1: Sector wise power consumption in India [1]

The Indian power sector has made tremendous progress since independence in making power availability to widely distributed geographical boundaries of the country. However, due to various constrains, the demand always over stepped the power, resulting into power shortages in the past years.

Hydropower is the most promising among all the renewable energy sources. It is a clean source of power produced when the water turns a hydraulic turbine. It provides the electricity essential for the economic and social development of the society. The most important fact to be noticed is that the maximum potential of the hydropower is yet to be harnessed in many countries. Though hydropower development started with small units in the beginning, attention was diverted to harnessing medium and small hydro because of their comparative economics.

India has a large potential in the medium and large projects. The inherent drawbacks associated with large hydro are the large gestation period, large area along with the vegetation has to be submerged which results in relocation as recently happened in the Tehri Hydro Power Plant. Political and environmental implications have compelled the planners to think for some other alternative of this large hydro resulting in the emergence of small hydro.

India has a history of 100 years of Small Hydro since its first installation of 130 kW at Darjeeling in the year 1897.India has one of the world's largest Irrigation Canal networks with thousands of Dams and Barrages. It has monsoon fed, double monsoon fed as well as snow fed rivers and streams with perennial flows. An estimated potential of about more 15,000 MW [1] of small hydro power projects exists in India. World installed capacity of small hydro today is around 50,000 MW against an estimated Potential of 180,000 MW. A general scenario of Small Hydro installed capacity worldwide is as under:

Table 1.1: Small Hydro Installed Capacity Worldwide [2]

COUNTRY	INSTALLED CAPACITY(MW)
India	2,181
Japan	3,900
China	15,000
Rest of Asia	400
Europe	9,000
Rest of the world	20,000
Total	**50,000**

There is a general tendency all over the world to define Small Hydro by Power Output. Different Countries have different norms keeping the upper limit ranging from 5 to 50 MW as shown in Table 1.2. In India, small hydro schemes are further classified by the central Electricity Authority (CEA) as shown in Table 1.3.

Table 1.2: International Definition of Small Hydro [4]

COUNTRY	DEFINITION (MW)
UK (NFFO)	< 5
UNIDO	< 10
Sweden	<15

Colombia	<20
Australia	<20
India	<25
China	<25
United States	<30
Brazil	<30
Philippines	<50
New Zealand	<50

Table 1.3: Classification of Small Hydro Schemes [5]

TYPE	STATION CAPACITY	UNIT CAPACITY
Micro Hydro	Up to 100 kW	Up to 100 kW
Mini Hydro	101 kW to 2000 kW	101 kW to 1000 kW
Small Hydro	2001 kW to 25000 kW	1001 kW to 5000 kW

The classification of small hydro power on the basis of station capacity is given by MNRE.

Table 1.4 Classification based on head [5]

TYPE	RANGE OF HEAD
Ultra Low Head	Below 3 m
Low Head	3 to 40 m
Medium/ High Head	Above 40 m

1.2 IMPORTANCE OF MICRO HYDRO POWER

Micro hydro is the subset of small hydro with capacity up to 100 kW [2]. Micro hydro is an important player in the remote, hilly and unelectrified areas of India where there is a substantial potential that can be tapped. Thus, micro hydro is an answer to the rural electrification in the remote areas where potential exists. There are huge potential available in the micro hydro range and it is ready to be harnessed. The current concern on the global environment has imposed a new constraint on the production of electricity. The emphasis is put on the development of environmental friendly form of energy to promote the sustainable social development. It is in these circumstances that the micro hydro power is drawing more attention. A rural population is scattered and unaware of the technological developments. For such areas, the isolated micro-hydro power plants are the least cost options. This is mainly because the other options for supply such as grid extension, diesel power, etc are more expensive and difficult to install or operate in the long run.

Since small water streams are usually available in the most of the hilly region, micro-hydro power plants can easily meet the needs of small village or cluster of settlements. These needs may be in the form of electricity or motive power to be used for agro processing, wood working and for the other small scale industries.

Apart from numerous advantages that the micro hydro schemes offer there is some drawbacks associated with it also. Two of the most common drawbacks of micro hydro installations are lack of economical viability and inappropriate capacity. In the former case the installation either falls in disrepair or will sooner or later stop being operational or it drains resources which could be put to much better use. In the latter case, the installations will either not be able to meet the demand or it will not be used to its full potential, resulting in the waste of capital.

1.3 TYPES OF SHP SCHEMES

Small Hydropower can also be broadly categorized in three types as follows:

1.3.1 Run-Of River Scheme

Run-of River hydroelectric schemes are those, in which water is diverted towards power house, as it comes in the stream. Practically, water is not stored during flood periods as well as during low electricity demand periods, hence water is wasted. Seasonal changes in river flow and weather conditions affect the plant's output. After power generation water is again discharged back to the stream. Generally, these are high head and low discharge schemes. The typical run-of river scheme is shown in Fig. 1.2.

1.3.2 Canal Based Scheme

Canal based small hydropower scheme is planned to generate power by utilizing the fall in the canal. These schemes may be planned in the canal itself or in the bye pass channel. These are low head and high discharge schemes. These schemes are associated with advantages such as low gestation period, simple layout, no submergence and rehabilitation problems and practically no environmental problems. The typical canal based scheme is shown in Fig. 1.3.

1.3.3 Dam Toe Based Scheme

In this case, head is created by raising the water level behind the dam by storing natural flow and the power house is placed at the toe of the dam or along the axis of the dam on either sides. The water is carried to the powerhouse through penstock. Such schemes utilize the head created by the dam and the natural drop in the valley. Typical dam toe based scheme is shown in the Fig. 1.4.

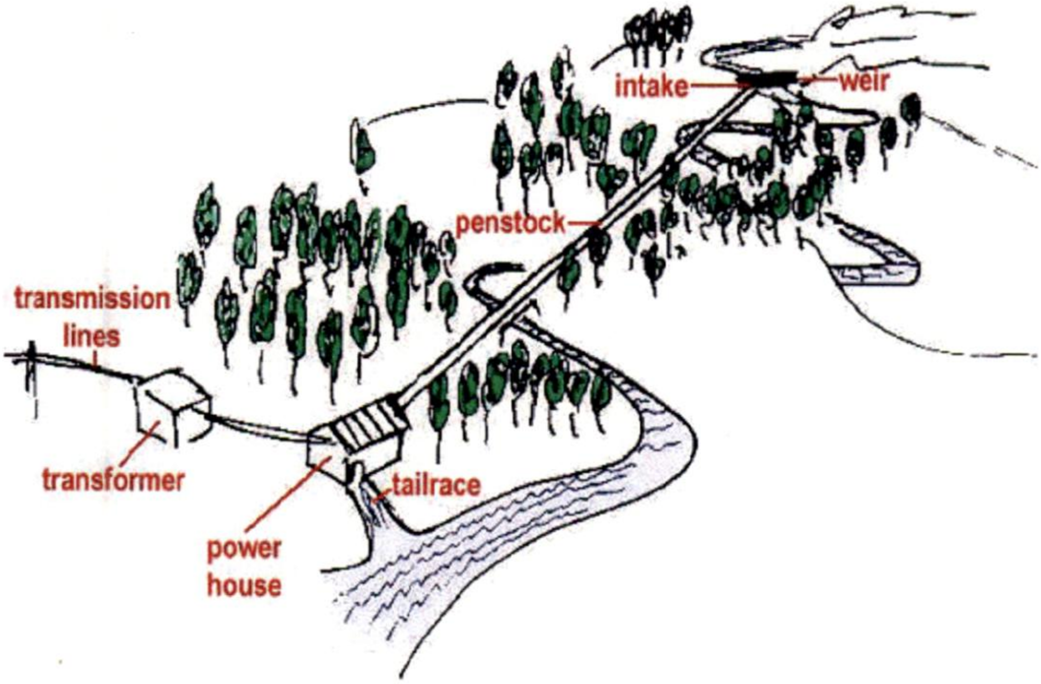


Fig. 1.2: Typical arrangement of run-off river scheme [6]

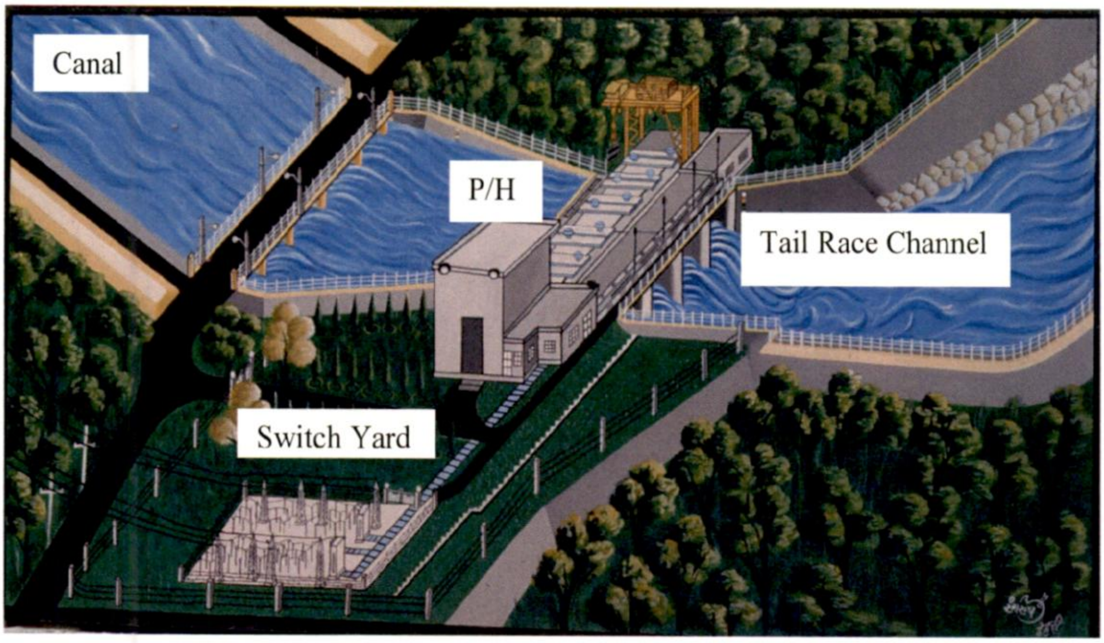


Fig. 1.3: Typical arrangement of canal based scheme [7]

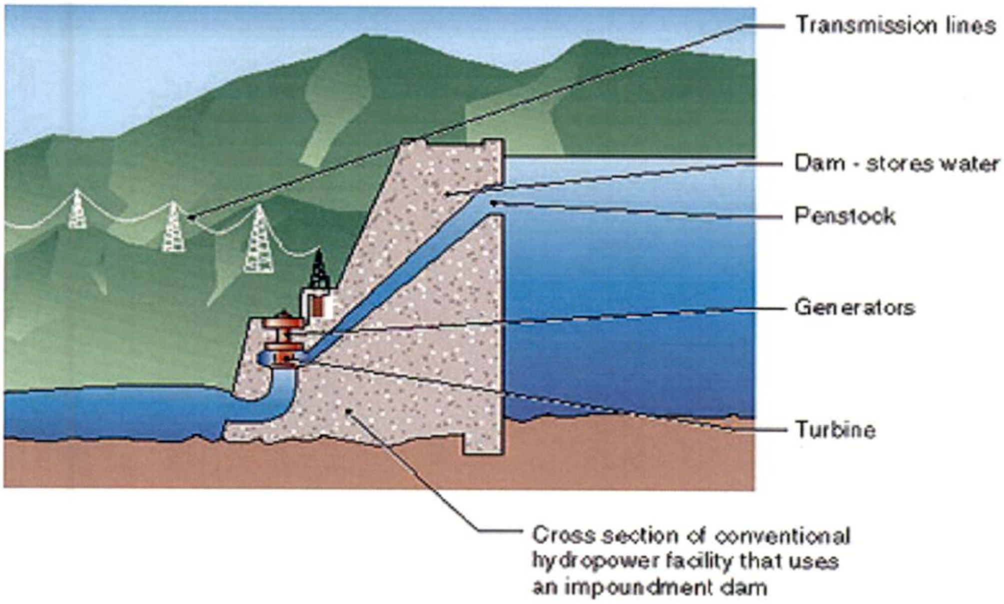


Fig. 1.4: Typical arrangement of dam toe based scheme [6]

1.4 HYDRO POWER TECHNOLOGY

Hydro power is obtained from the potential and kinetic energy of water flowing from a height. The energy contained in the water is converted into electricity by using a turbine coupled to a generator. The hydro power potential of a site is dependent on the discharge and head available at the site. The Power is estimated by the following equation: [4]

$$\text{Power (P)} = \rho \times g \times Q \times H \times \eta \text{ Watts} \tag{1.1}$$

where, ρ is density of water, g is acceleration due to gravity, Q is discharge in m^3/s, H is head in m and η_o is overall efficiency of the turbine, generator and gear-box

The head is relatively constant in run-of-river schemes except for variation in friction losses, with the varying discharge. Whereas, in canal based and dam toe based schemes head also varies depending on water releases and season of release. The design head is so selected that turbine is operated to the maximum time giving optimum energy generation. Energy generation per year is given as:

Energy Generation per Year = Power (kW) × Time in hours per year (1.2)

1.5 DIFFERENT COMPONENTS OF SHP

The schematic diagram of Run-of River (ROR) hydropower plant is shown in Fig. 1.4.The various components can be categorized in two parts.

i. Civil works components

ii. Electro- mechanical equipments

1.5.1 Civil Works Components

The purpose of civil work components is to divert the water from stream and convey towards the power house. In selecting the layout and types of civil components, due consideration should be given to the requirement for system reliability.

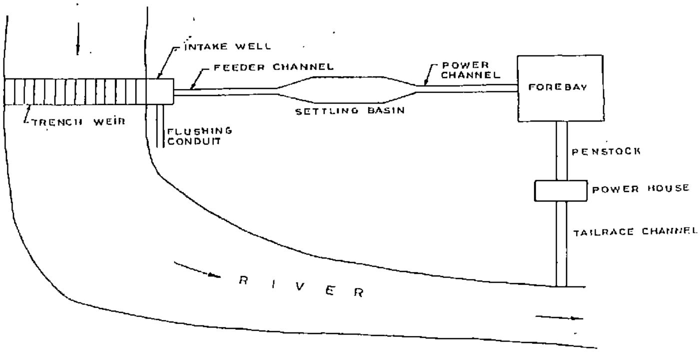


Fig. 1.5: Schematic diagram of run-of river plant [8]

1.5.2 Electro Mechanical Equipments

Electro-Mechanical equipments mainly include hydro turbine, generator, speed increaser, governor, gates and valves and other auxiliaries.

1.6 LITERATURE REVIEW

Khosrowpanah S, (1984) [9] carried out a study of cross flow turbine experimentally by varying the number of blades, the runner diameter, and the nozzle entry arc under flow-head variations. It was seen that maximum efficiency of the cross flow turbine at any flow/head combination increases as the nozzle entry arc increases or the aspect ratio of the runner decreases. Formulations were suggested to obtain the optimum number of blades for maximum efficiency of the turbine and to find the specific speed of the cross flow as a function of unit discharge and nozzle entry arc.

Desai and V. Rangappayya [10] carried a parametric study of cross flow turbine analysis to find out the key parameters influencing the turbine efficiency. One physical parameter (flow rate) and six geometric parameters (angle of water entry, diameter ratio, number of blades, flow stream spreading, runner aspect ratio, and blade exit angle) were identified as key parameters. A total of 39 runners and 11 nozzles were tested in 75 different combinations. The experimental investigation included measurements of torque, speed, flow rate and total head in physical models of turbine and nozzles. The theoretical analysis was based on the principles of dynamics and resulted in a simplified linear relationship between the shaft torque and speed. The results indicated that theoretical analysis can be used only as a preliminary predictive technique for maximum turbine efficiency, as verified by the experimental data. Multiple regression and probability analyses are performed to quantify the impact of the parameters on the cross-flow turbine efficiency. For the best nozzle-runner combination, the maximum efficiency maximum was determined as 88.0% with an uncertainty of +/- 2.4%, which was an improvement over the claimed maximum efficiency reported in the literature. The analysis of the experimental data clearly identifies parametric ranges in which efficiency can be improved. These results suggested that by careful choice of design parameters, the cross-flow turbine can be made as efficient as other traditional turbines; yet has the advantage of low cost and simple structure.

Parametric study on the performance of cross flow turbine was done by C.B. Joshi et al. [11]. In this experimental study the effects of blades number, nozzle entry arc, and the head on the performance characteristics of a cross flow turbine were investigated. It was observed that the efficiency of the turbine increases with the increase in blade number, Head and nozzle entry arc. The study also shows that there is an optimum value for the number of blades for a given nozzle entry beyond which the performance of cross flow turbine deteriorates.

Effect of draft tube size on the performance of a cross-flow turbine was studied by H. Reddy et al. [12]. Banki first used draft tube in 1998 (More & Merryfield, 1994) by modifying Michell's design and converted part of the residual velocity at the exit into additional kinetic energy. Gautschi et al. (1980) found that the draft tube had an adverse effect on the performance of a cross-flow turbine and that the efficiency decreased with increasing head. Johnson (1983) studied a cross flow turbine with a draft tube at the University of Rhode Island and concluded that the overall efficiency decreased with increasing head. Nakase et al. (1982) of the University of thokshima in Japan, studied that the cross-flow turbine is not a pure impulse turbine due to the presence of residual static pressure at the nozzle exit. Albertson et al. (1984) [13] concluded that the machine is not pure impulse turbine. Van Dixhorn et al. (1929) observed that maximum efficiency decreased with increasing head.

Joshi [14] conducted test on a 5 kW cross flow turbine at IIT Delhi, India and demonstrated that the addition of the draft tube increases efficiency at lower heads but that the efficiency deteriorated at higher heads.

Initial test revealed that the 203-mm draft tube was undersized and could not handled flows at higher heads, leading to deterioration in performance. Proper sizing of the draft tube for a cross-flow turbine is a difficult task due to the absence of established theory, unlike the case of reaction turbine. Hence, two new draft tube of 250 mm and 300 mm size were designed, keeping the same inlet to outlet diameter ratio of 1.4 the result pointed put that the cross-flow turbine is an impulse type machine. However, the existence of residual static pressure at the nozzle exit as demonstrated during the tests indicates that this machine is not pure impulse turbine. The draft tube, if properly sized, has a positive effect on the performance at all heads. The maximum efficiency decreases gradually with increasing head due to increased turbulence and losses and to the runner being partly flooded at higher heads.

Nozzle flow in a cross flow turbine was studied by N. H. Costa Pereira and J. E. Borges [15]. An investigation of the flow inside the nozzle of a cross flow turbine, which is a hydraulic turbine where the rectangular water jet coming from the nozzle crosses the rotor blades twice. Part of the investigation consisted in the experimental measure mental of the static pressure distribution on the inside walls of two different nozzle configurations, both with the nozzle mounted alone and in the presence of a rotor. The tests performed in the presences of a rotor included the measurement of efficiency and covered a wide range of working conditions around the best efficiency point. The analysis of the results gave an indication of the influence of the turbine non-dimensional volume flow rate on the flow inside the nozzle and the way it affects the reaction degree of the machine and its efficiency level. Although most of the tests were carried out with a 25-blade rotor, one of the analyzed nozzle configurations (that with an inside vane) was also tested with a 10-blade rotor, permitting the assessment of the effect the number of blades has on the flow in the nozzle.

The flow inside the nozzle with no inside vane was numerically analyzed by using a method based on a schwarz-christoffel conformal transformation of variables. The numerical results show a fair agreement with the experimental data collected when the rotor was not present. The measured data for the efficiency and non-dimensional pressure distribution coefficient showed no significant effect of the head as was to be expected. The presence of a rotor induced some changes in the pressure distribution which varied significantly with non-dimensional volume flow rate. It can be said that overall pressure level inside the nozzle tended to increase when the non-dimensional flow rate decreased, implying a bigger departure from pure impulse conditions as the non-dimensional volume flow rate is decreased. However, for peak efficiency conditions, the influence of the rotor is not large, and it depends on the configuration being tested and more specifically, on the pressure tapping being analyzed. No general trend was detected as a consequence of changing the number of rotor blades, from25 blades to 10 blades, because most of the changes are small, and depend markedly on the position of the point considered, being more pronounced in the walls that face the rotor more directly.

A comparison was done between the pressure distribution measured on the nozzle without inside vane, without any rotor mounted, and some numerical predictions calculated using a method based on a schwarz-christoffel conformal transformation of variables. A fair agreement between both sets of result was demonstration, which justifies the use of the numerical calculations for a qualitative discussion of some of the losses attributed to the nozzle, providing in this way a possible explanation for the poor performance of the analysed nozzle. It was thought that the numerical calculations constitute a useful tool that could guide us to the alteration to be made to obtain more efficient nozzle design.

Investigation of the performance of a cross flow turbine was made by Hayati Olgun [16]. An experimental investigation was conducted to study the effects of some geometric parameters of runners and nozzles (e.g., diameter ratio and throat width ratio) on the efficiency in the cross-flow turbines, by varying of ratio of inner-to-outer diameters of runners and gate openings of two different turbine nozzles under different heads. In the study four different types of runners (170 mm outer diameter, 114 mm width) were designed and manufactured to investigate the effects of the ratio of inner-to-outer diameters of runners on the turbine efficiency. Each runner had 28 blades and the ratios of inner-to-outer diameters of runners were 0.75, 0.67, 0.58 and 0.58, respectively. The runners were denoted with the numbers 1, 2, 3 and 4, and nozzle A and B, the blades inlet and outlet angles were selected as 30° and 90°. Nozzles A and B were of rectangular cross-sectional channels. Nozzle outlet angles of two solid walls of 16° were measured from the circumferential direction. The performance parameters namely output power, efficiency, runaway speed, reduced speed and power for different nozzle/runner combinations were investigated by changing head range from 8 to 30 m, the nozzle A-runner combinations (A-1,2,3,4) and from 4 to 17 m, the nozzle B-runner combination (B-2) at different gate openings. The results of the study clearly indicated that there was a negligible difference (e.g., 3% in total between 0.54 and 0.75 diameter ratio) in the efficiency of turbine for different diameter ratios and heads, and that the highest efficiency was obtained as 75% for A-2.

Effect of interior guide tubes in cross flow turbine runner on turbine performance was studied by, Hayati Olgun[17]. In the study interior guide tubes were designed used inside the runner of a cross-flow turbine to collect and guide the crossing flow towards the second stage of the runner. The interior guide tubes were designed on the basis of observed flow patterns inside the runner. Experimentally, three different types of tubes were tested. The tests were conducted to calculate the turbine efficiency with different gate openings of nozzle and different positions of interior guide tubes. From the experimental results, it was seen that the guide tube needs to be carefully designed for the operating conditions of the cross-flow turbine. The guide tubes used in the experiment did not improve the turbine efficiency due to chocking effect. The maximum efficiency thus obtained was 64%. Using the interior guide tubes, the maximum efficiency obtained was decreased from 75% to 65%, because of increasing friction and choke losses in the runner. It can be assumed that the major portion of flow rate does not follow the suitable pathway. The interior guide tube A with position -10°, is more efficient than the other positions.

The cross flow turbine has a through shaft for the rotation of the runner. It is observed that the size of this shaft offers resistance to the flow in between two stages. This study intends to see the flow pattern obtained by varying the size of the shaft. The results of this analysis can be used to study the flow pattern in a cross flow runner for suggesting improvements.

1.7 OBJECTIVE OF PRESENT STUDY

The present work was proposed to carry out the design modification of cross flow turbine using interior guide tube. Following are the objectives of the present study:

i. To design and fabricate the runner for the given data and testing the efficiency of turbine.
ii. To design and install interior guide tube in the runner to guide the water for second stage.

CHAPTER-2

TURBINES USED FOR MICRO HYDRO

2.1 GENERAL

The idea of using water as source of energy existed more than 2,200 years ago. The hydraulic energy was first produced in Asia (China and India) in the form of mechanical energy, by passing water through a water wheel. The old type of water wheel made mainly from wood, still exist in India. Such type of prime movers were taken from the Asian Continent to Egypt and then from there to European countries and America. The actual design of water wheel was first made by Leonardo da Vinci (1452 to 1519 AD), which he did with hand sketches. The theory and mathematical solutions of such wheels were drawn by scientists Galileo Galilei and Descartes. A Swiss scientist Daniel Bernoulli first wrote a theory for the conversion of water power into other forms of energy. In 1824, a French scientist named Burdin designed a radial water wheel with a guide mechanism which could be in practical field and was the first machine named as water turbine. Burdin could not make much fame of his work, and this turbine was further developed in designs by his student Fourneyron in 1827 which is the first water turbine [26].

A turbine converts energy in the form of falling water into rotating shaft power. The selection of the turbine for any particular hydro site depends on the site characteristics, the dominant ones being the head and flow. Selection of turbine also depends on the desired speed of the generator or other device loading the turbine. Other considerations such as whether the turbine is expected to produce power under part-flow conditions also play an important role in the selection. All turbines have a power-speed characteristic. They will tend to run most efficiently at a particular speed, head and flow combination.

The head under which it operates largely determines a turbine design speed. Turbines can be classified as high head, medium head or low head machines. Turbines are also divided by their principle way of operating and can be either impulse or reaction turbines. The general classification is given in Table 2.1

Table 2.1: Classification of turbines [27]

Turbines	High head	Medium Head	Low Head

Impulse	Pelton Turgo	Cross flow Multijet pelton Turgo	Cross flow
Reaction		Francis	Propeller Kaplan

The rotating element (called `runner') of a reaction turbine is fully immersed in water and is enclosed in a pressure casing. The runner blades are profiled so that pressure difference across them imposes lift forces, which cause the runner to rotate. In an impulse turbine runner operates in air, driven by a jet (or jets) of water. Here the water remains at atmospheric pressure before and after making contact with the runner blades. In this case a nozzle converts the pressurized low velocity water into a high speed jet. The runner blades deflect the jet so as to maximize the change of momentum of the water and thus maximizing the force on the blades.

Impulse turbines are usually cheaper than reaction turbines because there is no need for a special pressure casing.

2.2 IMPULSE TURBINES

Impulse turbines are more suitable for micro-hydro applications compared with reaction turbines because of the following advantages:

i. Greater tolerance of sand and other particles in the water,
ii. Better access to working parts,
iii. No pressure seals around the shaft,
iv. Easier to fabricate and maintain,
v. Better part-flow efficiency.

The major disadvantage of impulse turbines is that they are mostly unsuitable for low-head sites because of their low specific speeds. The cross flow, turgo and multi-jet Pelton are suitable at medium heads.

In most of the micro-hydro power systems operating today either have the cross-flow turbine or single to multi-jet Pelton wheel depending on the heads and flow normally encountered. The reason for using these turbines is the advantages offered by these in comparison to the rest of the impulse turbines.The runner of Pelton turbine is shown in fig 2.1.

i. They are the simplest impulse turbines in construction, operation and maintenance.

ii. Multi-nozzle Pelton-wheel and partitioned cross-flow turbines have generally good part load efficiencies and hence can cope with considerable flow variations normally occurring in micro-hydro systems.

iii. At high head Pelton wheel is the most efficient device among the impulse turbines and for a given head and power output cross- flow turbine covers the widest range of application(2-200m) among the several types of turbines that are available and yet offers reasonably good efficiency within this range.

iv. Their floor space requirements are comparatively small.

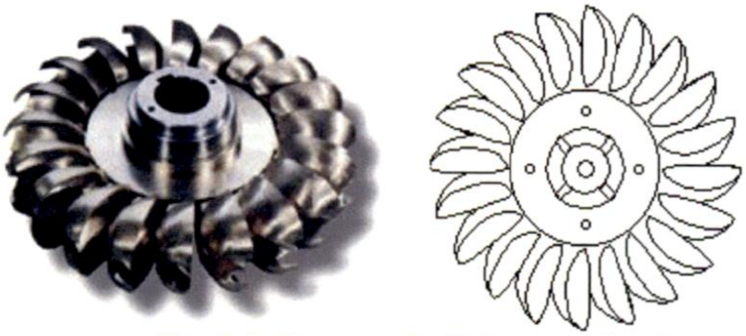


Fig. 2.1: Runner of a Pelton turbine[27]

2.2.1 Turgo impulse turbines

The Turgo turbine is an impulse machine similar to a Pelton turbine but designed to have a higher specific speed. In this case the jets aimed to strike the plane of the runner on one side and exit on the other. Therefore the flow rate is not limited by the discharged fluid interfering with the incoming jet (as is the case with Pelton turbines). As a consequence, a turgo turbine can have a smaller diameter runner than a Pelton for an equivalent power. With smaller faster spinning runners, it is more likely to be possible to connect turgo turbines directly to the generator rather than having to go via a costly speed-increasing transmission. Water impingement on a typical turgo runner is shown in Figue2.2. Like the Pelton, the turgo is efficient over a wide range of speeds and shares the general characteristics of impulse turbines listed for the Pelton, including the fact that it can be mounted either horizontally or vertically. A turgo runner is more difficult to make than a Pelton and the vanes of the runner are more fragile than Pelton buckets. At one time they were exclusively made by Gilbert, Gilkes and Gordon a

UK manufacturer who owned the patent rights, but these are now manufactured in several other countries.

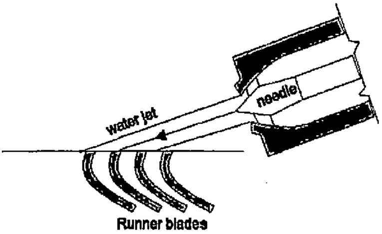


Fig 2.2: Water jet impingement on the turgo runner [27]

2.2.2 Cross flow turbines

Cross flow turbine also called a Michell-Banki turbine. A cross flow turbine has a drum-shaped runner consisting of two parallel discs connected together near their rims by a series of curved blades. Cross flow turbine always has its runner shaft horizontal (unlike Pelton and Turgo turbines which can have either horizontal or vertical shaft orientation).

2.2.3.1 Operation of cross flow turbine

In operation, a rectangular nozzle directs the jet onto the full length of the runner. The water strikes the blades and imparts most of its kinetic energy. It then passes through the runner and strikes the blades again on exit, impacting a smaller amount of energy before leaving the turbine. Although strictly classed as an impulse turbine, hydro dynamic pressure forces are also involved and a mixed flow definition would be more accurate.

2.2.3.2 Part flow efficiency

A high part-flow efficiency can be maintained at less than a quarter of full flow by the arrangement for flow portioning illustrated in the Fig2.3. At low flows, the water can be channeled through either two-thirds or one third of the runner, thereby sustaining a relatively high turbine efficiency. The part load efficiency graph is shown in Fig. 2.3.

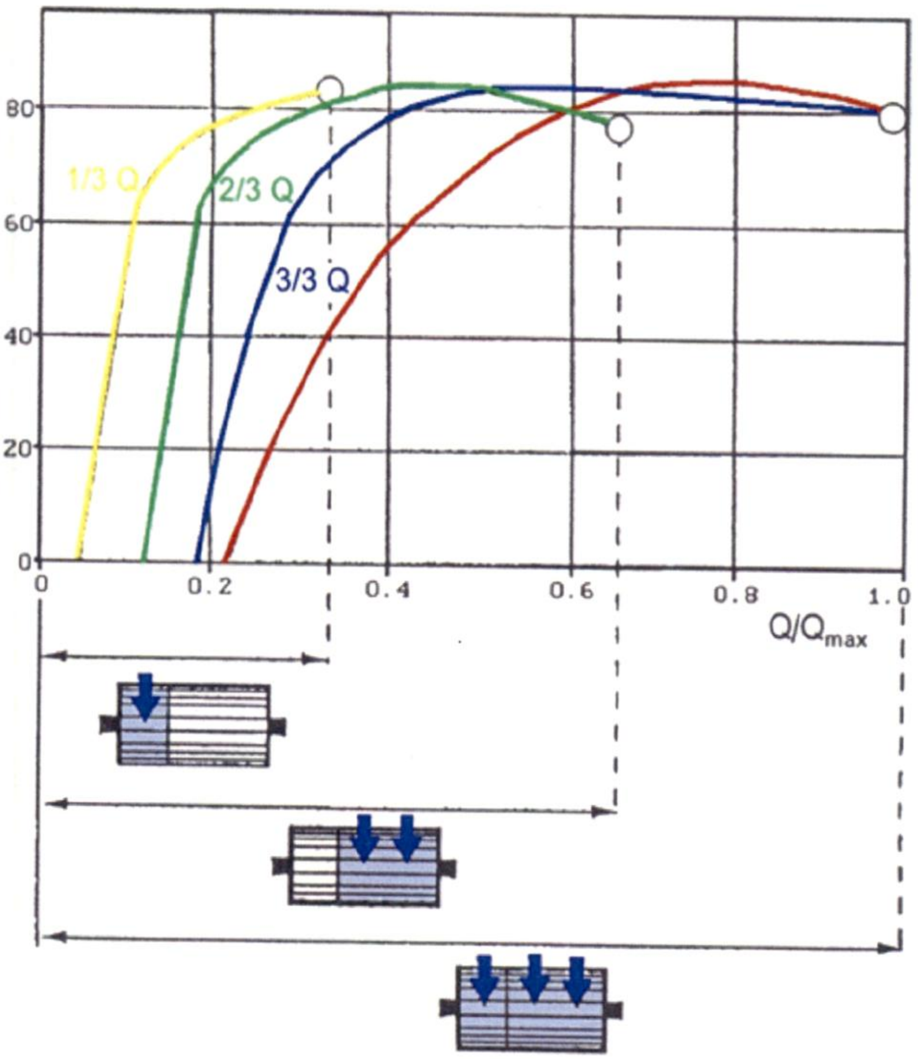


Fig. 2.3: The part load efficiency of cross flow turbine [26]

2.3 REACTION TURBINES

The reaction turbines considered here are the Francis turbine and the propeller turbine and the Pump as Turbine. In all reaction turbines, specific speed is high, i.e. reaction turbines rotate faster than impulse turbines given the same head and flow conditions. This has the very important consequences that a reaction turbine can often be compiled directly to an alternator without requiring a speed-increasing drive system. Some manufacturers make combined turbine-generator sets of this sort. Significant cost savings is made in eliminating the drive and the maintenance of the hydro unit is very much simpler. The Francis turbine is suitable for medium heads, while the propeller is more suitable for low heads.

On the whole, reaction turbines require more sophisticated fabrication than impulse turbines because they involve the use of larger and more intricately profiled blades together with carefully profiled casings. The extra cost involved is offset by high efficiency and the advantages of high running speeds at low heads from relatively compact machines. Fabrication constraints make these turbines less attractive for use in micro-hydro in developing countries. Nevertheless because of the importance of low head micro-hydro, work is being undertaken to develop propeller machines which are simpler to construct. Most reaction turbines tend to have poor part-flow efficiency characteristics.

2.3.1 Francis turbine

Francis turbines can either be volute-cased or open-flume machines. The spiral casing is tapered to distribute water uniformly around the entire perimeter of the runner and the guide vanes feed the water into the runner at the correct angle. The casing is shown in the Fig.2.4 The runner blades are profiled in a complex manner and direct the water so that it exits axially from center of the runner. In doing so the water imparts most of its pressure energy to the runner before leaving the turbine via a draft tube.

The Francis turbine is generally fitted with adjustable guide vanes. These regulate the water flow as it enters the runner and are usually linked to a governing system which matches flow to turbine loading in the same way as a spear valve or deflector plate in a Pelton turbine. When the flow is reduced the efficiency of the turbine falls away.

2.3.2 Propeller turbine

The propeller turbine, is suitable for use on low to medium head sites (1.5-15m). This simple fixed runner blade, fixed guide vane turbine is only of limited use, as its efficiency falls off sharply from its nominal operating conditions.

However, most of the disadvantages of the simple propeller turbine can be overcome by the use of adjustable blades. When on site, variation in flow is considerable, it may be economical to install two different sizes of propeller turbines. This allows for a low cost installation to best utilize the flows by operating the turbines in conjunction with each other.

The basic propeller turbine consists of a propeller, similar to a ship's propeller, fitted inside a continuation of the penstock tube. The turbine shaft passes out of the tube at the point where the tube changes direction. The propeller usually has three to six blades, three in the case of very low head units and the water flow is regulated by static blades or swivel gates ("wicket gates") just upstream of the propeller. This kind of propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor blades cannot be changed. The part-flow efficiency of fixed-blade propeller turbines tends to be very poor.

2.3.2.1 Types of propeller turbine

a) **Tubular Turbines:** Tubular turbines are horizontal or slant mounted units with propeller runners. The generator is located outside of water passage. Tubular turbines available are equipped with fixed or variable pitch runner and with or without wicket gate assembly. The advantage of tubular turbines is the accessibility of generator and gear for maintenance

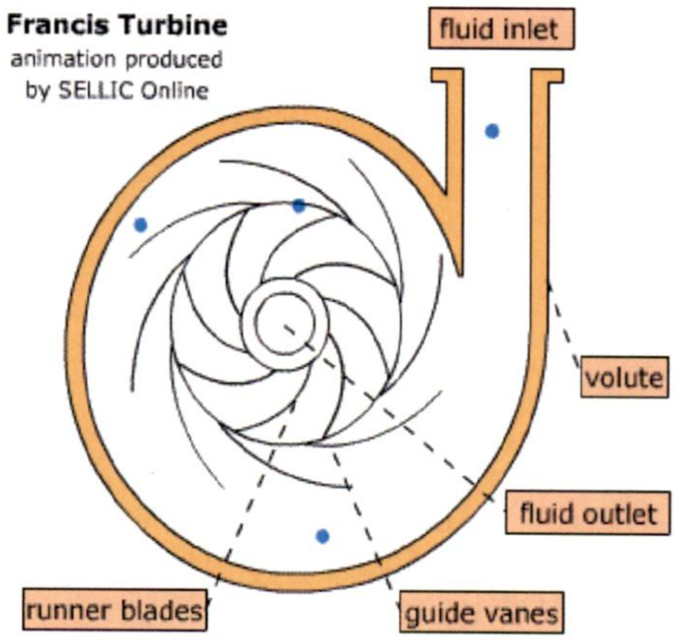


Fig. 2.4: Francis turbine casing [26]

b) **Bulb Turbines:** In bulb turbines generator is enclosed within the bulb. The bulb unit is placed horizontally completely submerged in water passage. The turbine is axial flow type and is not used for micro range. These turbines have high specific speed.

c) **Rim or Straw Flow Turbines:** A Rim turbine is one in which the generator rotor is mounted on the periphery of the turbine runner blade. In this the limitation on capacity is imposed by design of the seal which prevents the leakage of water into the generator.

2.4 PUMP AS TURBINE (PAT)

In micro hydro range the pumps can be used as turbine. The reason of this substitution being:

i. Low cost owing to mass production of pumps

ii. Local production and availability of spare parts.

iii. For output less than 10kW the cost of a PAT is likely to be significantly lesser than as compared to a cross flow or Pelton turbine.

iv. It is easy to install.

The layout of a PAT scheme is shown in the Fig. 2.5. Centrifugal pump can be used as turbine by passing water through them in reverse mode. Research is currently being done to enable the performance of pumps as turbines to be predicated more accurately. The disadvantages are the as yet poorly understood performance characteristics and very poor part-flow efficiency. Centrifugal pumps from radial flow to axial flow can be operated in reverse as turbines throughout the head capacity and speed range as an efficient turbine.

The classification of PAT's is as given below:

a) Radial flow pumps-Nsp-10 to 40

b) Mixed flow pump with outlet edge parallel to machine axis Nsp-40-80

c) Mixed flow with outlet edge inclined to the machine axis with volute casing Nsp-80-160.

d) High specific speed mixed flow pumps delivering axially Nsp (100-1000).

The main elements of a MHP (Micro Hydro Power) scheme using PAT are.

i. Intake

ii. Settling basin

iii. Head race channel or conduit

iv. Forbay: The function of forebay is to

   a. Settling of the particles which may cross the desilting basin.

   b.Removing floating debries

   c. Protecting HRC from excessive change in water level caused by flow variation

v. Penstock

2.5 THE GHARAT AND THE MPPU

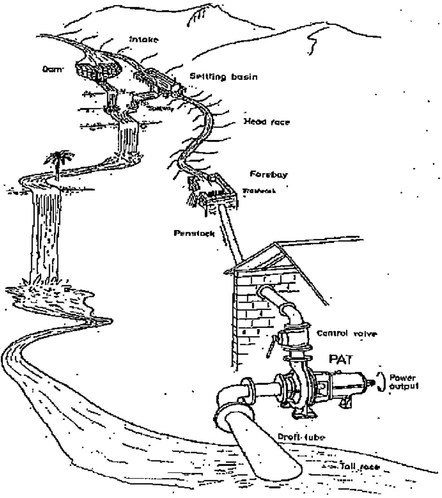


Fig. 2.5: PAT scheme layout [21]

2.5.1 Gharat or water mill

Gharats have momentous role in generation of mechanical output from water stream. The output taken from the water mill is mostly mechanical, but the development in this field can increase its usage for electricity generation. At an average a gharat produces 2kW power in the hilly region and can be increased upto 5kW with an efficiency of 15-18%. The types of watermills are classified as:

1. **Vertical shaft**: it has a wooden turbine wheel fitted to a thick wooden shaft which is tapered at both the ends. The water is diverted to wheel by a wooden chute or open

channel. The wooden shaft is supported on a stone pivot through a steel pin and held in the sliding bearing at the top.

2. **Horizontal shaft:** It consists of a circular runner made of two wooden disks mounted on a steel shaft. The shaft is supported on the stone bearing at both the ends. This mill drives machine through belting. The output is taken for driving
    - i. Grinding wheel
    - ii. Rice dehusking machine &Oil expeller
    - iii. Saw mill

It is higher in cost with respect to vertical type mill also the efficiency is low.(18-20%)

There is another classification of water mill, which is according to the position of the water wheel.

i. Over shot water wheel
ii. Under shot water wheel
iii. Baker wheel
iv. Breast water wheel

CROSS FLOW TURBINE

3.1 GENERAL

A cross flow turbine, Banki-Michell turbine, or Ossberger turbine is a water turbine developed by the Australian Anthony Michell, the Hungarian Donat Banki and the German Fritz Ossberger.

Michell obtained patents for his turbine design in 1903, and the manufacturing company Weymouth made it for many years. Ossberger's first patent was granted in 1922, and he manufactured this turbine as a standard product. Today, the company founded by Ossberger is the leading manufacturer of this type of turbine.

Unlike most water turbines, which have axial or radial flows, in a cross flow turbine the water passes through the turbine transversely, or across the turbine blades. Like a waterwheel, the water is admitted at its edge. After passing the runner, it leaves on the opposite side. Going through the runner twice provides additional efficiency. The cross-flow turbine is a low-speed machine. Although the illustration shows one nozzle for simplicity, most practical cross flow turbines have two nozzles arranged in a manner so that the water flows do not interfere [31].

Cross flow turbines are often constructed as two turbines of different capacity that share the same shaft. The turbine wheels have the same diameter, but different lengths to handle different volumes at the same pressure. The subdivided wheels are usually built with volumes in ratios of 1:2. The subdivided regulating unit (the guide vane system in the turbine's upstream section) provides flexible operation, with 1/3, 2/3 or 100% output, depending on the flow. Low operating costs are obtained with the turbine's relatively simple construction. Fig. 3.1 showing the Banki turbine with their components.

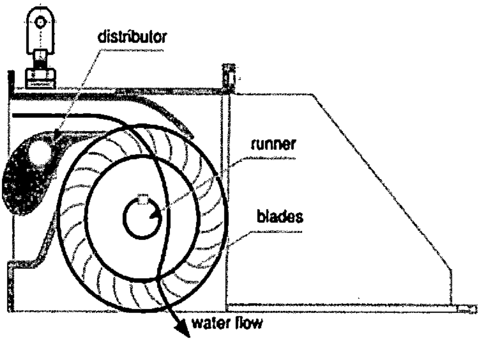


Fig.3.1: Banki turbine [23]

3.2 FEATURES OF CROSS FLOW

The turbine consists of a cylindrical water wheel or runner with a horizontal shaft, composed of numerous blades (up to 37), arranged radially and tangentially. The blade's edges are sharpened to reduce resistance to the flow of water. A blade is made in a part-circular cross-section (pipe cut over its whole length). The ends of the blades are welded to disks to form a cage like a hamster cage; instead of the bars, the turbine has trough-shaped steel blades.

The water flows first from the outside of the turbine to its inside. The regulating unit, shaped like a vane or tongue, varies the cross-section of the flow. The water jet is directed towards the cylindrical runner by a fixed nozzle. The water enters the runner at an angle of about 45 degrees, transmitting some of the water's kinetic energy to the active cylindrical blades.

The regulating device controls the flow based on the power needed, and the available water. The ratio is that (0–100%) of the water is admitted to 0-100% × 30/4 blades. Water admission is to the two nozzles is throttled by two shaped guide vanes. These divide and direct the flow so that the water enters the runner smoothly for any width of opening. The guide vanes should seal to the edges of the turbine casing so that when the water is low, they can shut off the water supply. The guide vanes therefore act as the valves between the penstock and turbine. Both guide vanes can be set by control levers, to which an automatic or manual control may be connected.

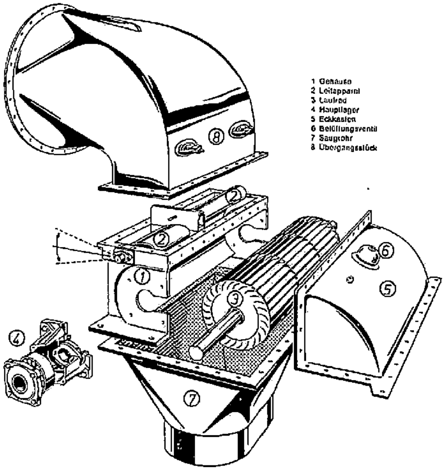


Fig.3.2: Ossberger turbine section [22]

The turbine geometry (nozzle-runner-shaft) assures that the water jet is effective. The water acts on the runner twice, but most of the power is transferred on the first pass, when the water enters the runner. Only 1/3 of the power is transferred to the runner when the water is leaving the turbine. The water flows through the blade channels in two directions: outside to inside, and inside to outside. Most turbines are run with two jets; arranged so two water jets in the runner will not affect each other. It is, however, essential that the turbine, head and turbine speed are harmonized. The Fig. 3.2 is the Ossberger turbine section.

The cross-flow turbine is of the impulse type, so the pressure remains constant at the runner. In the cross flow the water is directed into the blades tangentially at about mid way on one side. The flow of water "crosses" through the empty center of the turbine and exits just below the center on the opposite side. Thus the water strikes blades on both sides of the runner. It is claimed that the entry side contributes about 75% of the power extracted from the water and that the exit side contributes the remainder. The cross flow is an impulse turbine and requires a high head to be really efficient but it will "work" on heads as low as 1 m. It can be fabricated locally and many have been built. The designer of the locally manufactured claims about 60% efficiency. There are commercial built cross flow turbines that can deliver higher efficiencies, on ideal sites.

The cross flow turbine has a drum type runner on which the blades are arranged on the periphery of the supporting rings. Thus, the interior is hollow where the flow is free to flow. This empty space contains the shaft responsible for rotation of the runner due to the momentum transferred by the flow.

The cross flow turbine is mostly suitable for micro hydro power plants. These plants have the capacity ranging from 5 to 10 kW. The reason why cross flow turbine is suitable for these applications is that these turbines have low price, good regulation, excellent behavior with part loads, simple in construction and easy in maintenance.

Cross flow turbine is basically an impulse type turbine that is all pressure energy is converted into velocity energy in the nozzle itself. However, as the gap between nozzle and runner is very small, the pressure near the outlet of the nozzle is higher than atmospheric pressure, therefore, a small portion of energy is in the form of reaction. One such cross flow turbine is shown in Fig. 3.3.

As the flow enters the turbine through the nozzle, a portion of water jet hits the turbine blades twice, initially from outside the runner to the inside (i.e. the second stage). Since the water jet crosses the runner twice, it is called cross flow turbine. The remaining portion of the jet which crosses the runner only once is called the uncrossed flow.

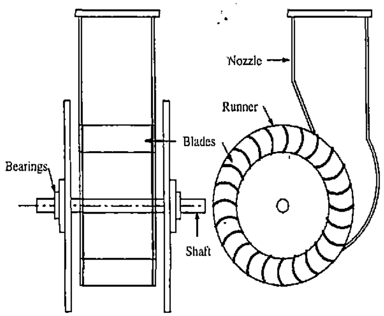


Fig. 3.3: Components of cross flow turbine [22].

3.3 IMPORTANT CHARACTERISTICS OF CROSS FLOW TURBINE

i. Because of symmetry of the blades the length of buckets can be increased up to any desired value and hence flow rate.
ii. Simple construction and easy to fabricate.
iii. It has almost flat efficiency curve. Thus, cross flow turbine can be operated at almost constant efficiency at varying load condition up to about 15% of the rated flow. Hence, turbine is used at low head and medium head where fluctuation is flow rate is high.
iv. It has comparatively low peak efficiency.
v. It has specific speed range from 15-70.
vi. Operation is convenient and maintenance is relatively easy.

3.3.1 Advantages

The peak efficiency of a cross flow turbine is somewhat less than efficiencies of other turbines. However, the cross flow turbine has a flat efficiency curve under varying load. With a split runner and turbine chamber, the turbine maintains its efficiency while the flow and load vary from 1/6 to the maximum.

Since it has a low price, and good regulation, cross flow turbines are mostly used in mini and micro hydropower units less than two thousand kW and with heads less than 200 m.

Particularly with small run-of-the-river plants, the flat efficiency curve yields better annual performance than other turbine systems, as small rivers' water is usually lower in some months. The efficiency of a turbine determines whether electricity is produced during the periods when rivers have low heads. If the turbines used have high peak efficiencies, but behave poorly at partial load, less annual performance is obtained than with turbines that have a flat efficiency curve.

Due to its excellent behavior with partial loads, the Cross flow turbine is well-suited to unattended electricity production. It's simple construction makes it easier to maintain than other turbine types; only two bearings must be maintained, and there are only three rotating elements. The mechanical system is simple, so repairs can be performed by local mechanics.

Another advantage is that it can often clean itself. As the water leaves the runner, leaves, grass etc. will not remain in the runner, preventing losses. So although the turbine's efficiency is somewhat lower, it is more reliable than other types. No runner cleaning is normally necessary, e.g. by flow inversion or variations of the speed. Other turbine types are clogged easily, and consequently face power losses despite higher nominal efficiencies.

The main advantage of the cross-flow turbines is easy and inexpensive construction. This is also ideal for small run-of the river operations at low and medium heads because its efficiency is much less dependent on the flow rate than other types of turbines. The cross flow turbine generally consists of a runner and an inlet nozzle as shown in Fig. 3.3. The runner is simply made of a series of radially curved blades connected by two circular parallel discs. The nozzle has a rectangular cross section and leads the water jet into the runner at the same angle.

3.3.2 Disadvantages:

i. Low efficiency.
ii. Recommended for "Micro-Hydro" range only.

3.3.3 The main characteristics of Cross Flow Turbine

i. Rotational speed can be selected in a wide range.
ii. Turbine diameter is independent of the flow rate.
iii. Satisfactory efficiency can be obtained.
iv. Manufacturing is simple and welding construction can be easily realized by local facilities.
v. Flow and power adjustment can be obtained by means of a guide vane located in the nozzle.
vi. The bearings have no contact with the flow.

The characteristics mentioned above make these turbines very suitable for use in regional small hydropower generation. An important design parameter of the runner is the selection of the optimum number of blades, inner-to-outer diameter ratio, blade angles and blade forms. The cross flow turbine has attracted the attention of several investigators working in the area of micro hydroelectric power generation.

3.4 PARTS OF CROSS FLOW TURBINE

A Cross-flow turbine consists of the following components:

A. Nozzle: It is an integral part of any impulse turbine. For a cross-flow turbine the nozzle is of rectangular shape whose width matches the width of the runner. Its primary function is to convert the total available head into kinetic energy and simultaneously convey the water to the runner blades at a desired angle. It is mounted at the exit of the main pipe line system and its exit is placed very close to the outer periphery of the turbine runner. Fig. 3.4 shows the nozzle of a cross flow turbine.

Fig. 3.4: Nozzle of Cross flow turbine [24]

B. Runner with blades: Runner is the central part of the whole turbine system and is responsible for the conversion of water energy into mechanical energy. Its design is very critical for achieving good overall performance of the turbine. It is designed in the shape of a barrel and consists of blades, rim and a shaft as shown in Fig. 3.5. It is positioned just downstream of the nozzle opening. Its main components are blades, shaft and bearing.

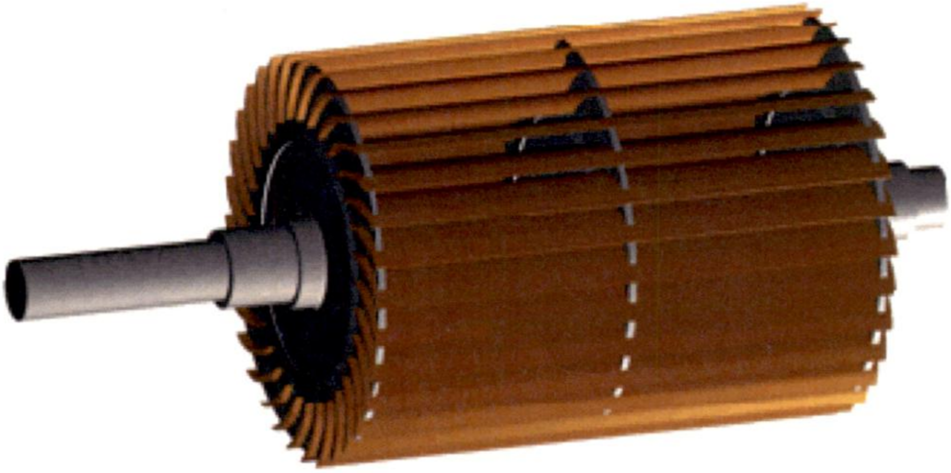


Fig. 3.5: Runner of Cross flow turbine [24]

Blades are curved and mounted between two circular rims parallel to the axis of the shaft. Their function is to change smoothly the direction of the incoming flow from the nozzle. Fig. 3.6 shows the blade of the cross flow turbine.

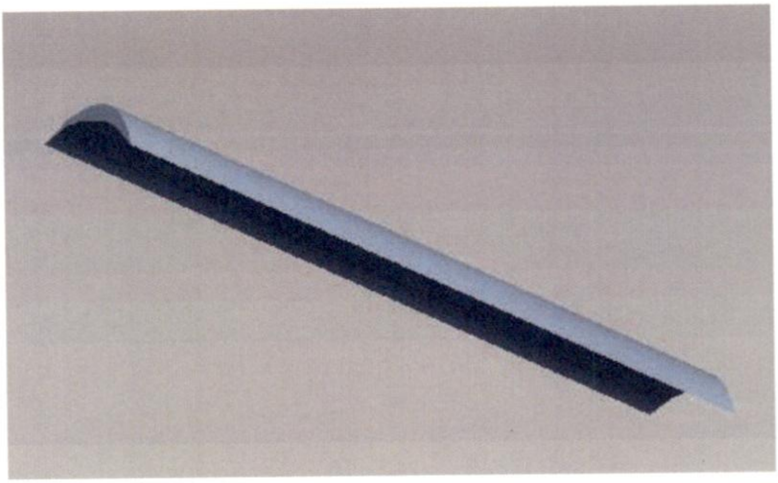


Fig. 3.6: Blade of cross flow turbine

C. Shaft: The shaft that is an integral part of the runner, transfers the torque generated to the generator or alternator. A correctly dimensioned shaft also allows the water jet to pass to the second stage without any hindrance.

D. Bearing: The primary function of the bearing is to hold the shaft rigidly on its position. At the same time it also reduces the resistance to the rotation of the shaft and absorbs the axial forces on it.

E. Casing: Casing is mainly used to prevent the splashing of water and channelize it to the draft tube. It's another function is to create near vacuum conditions for mounting the draft tube.

F. Draft Tube: The draft tube is used to recover a major portion of the residual energy left in the water flow coming out of the runner i.e., the head between the turbine and the tail water. The secondary function of the draft tube is to give a higher setting to the turbine plant, without losing the head, so that there is more freedom in the general arrangement of the plant and the power transmission than with an open discharge turbine.

G. Guide Vane: The function of the guide vane is to streamline the - desired quantity of flow to the runner. It can be controlled manually or automatically by a governor. By doing so the cross sectional area in the direction of flow is reduced and the flow is subjected to a continuous acceleration over a wide range of van openings. This guide vane is fitted into the nozzle.

H. Air Valve: Adjustable air operated by a float or spring loaded valve is used to control the water level in the housing. When a turbine with a draft tube is running, the air inside the housing is swept out so that a vacuum is formed and a suction column rises in the draft tube due to the external atmospheric pressure can be so large that the water level reaches the runner causing the water to wade. The principle of operation of this turbine is based on a broad jet of water passing twice through the rectangular openings between the adjacent blades of the runner. The water first strikes the turbine blade on the upper rim of the turbine, imparting most of its energy, passes through the center of the runner, strikes the blade on the lower rim, imparting again energy for the second time to the runner and finally discharges out of it into the tail water.

3.5 STEPS FOR THE DESIGN OF CROSS FLOW TURBINE

3.5.1 Site Data [5]

A typical site having following data is required for the design of cross flow turbine.

Design Head = H (m)
Design Discharge = Q (m^3/s)
Turbine Speed = N (rpm)

3.5.2 Steps of Design

Following are the steps in the design of a cross flow turbine runner.

3.5.2.1 Blade Geometry

Before moving on to the design of the turbine, it is important to understand the geometry of the blade as shown in Fig 3.1 and the various parameters are

R_1 is the outer radius of the runner
R_2 is the inner radius of the runner, locus at the end of the skeleton lines of the blades
β_1 is the outer blade angle
β_2 is the inner blade angle
r_b is the curvature radius of the blade
r_p is the pitch circle radius

δ is the segment angle of the blade

the following expressions are listed in the required order for calculating the parameters δ, r_p, r_b, based on the parameters R_1, R_2, β_1, β_2.

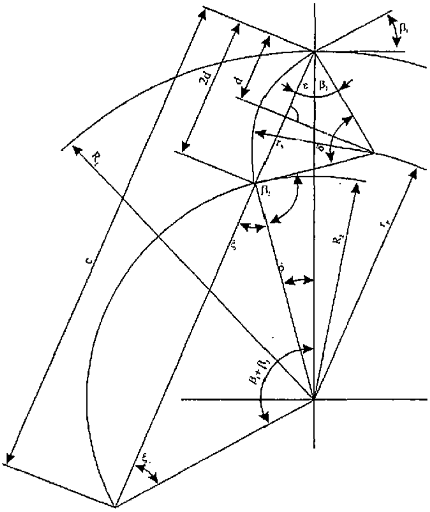


Fig 3.7: Geometry of Blades of Cross Flow Turbine (general)

$$\phi = \beta_1 + \beta_2 - (180 - 2\xi) \tag{3.1}$$

$$\partial = \frac{R_1 \sin\phi}{2\sin(180 - 2\xi)} \tag{3.2}$$

$$\delta = 180° - 2(\beta_1 + \varepsilon) \tag{3.3}$$

$$r_b = \frac{d}{\cos(\beta_1 + \varepsilon)} \tag{3.4}$$

$$r_p = \sqrt{r^2 + R_1^2 - 2r_b R_1 \cos\beta_1} \tag{3.5}$$

The logarithmically spiral is expressed by the formula:

$$r_\phi = e^{k\phi} \tag{3.6}$$

$$\text{K} = \cot k \tag{3.7}$$

(k>0)

Where,

r_ϕ = the distance of a point on the angle from the origin

e is the natural logarithm

K is cotangent of the angle between the tangent to the logarithmically spiral and its radius vector to the origin of the spiral = tan α_1.

ϕ is the angle expressed in radians between two points on the spiral and the origin of the spiral.

Equation below represents all the relevant parameters, influencing the discharge through the turbine. The flow admission area of a cross flow turbine is shown in fig.

$$Q = \frac{b_o 2R_1 \pi \phi^0 \sqrt{2gH}}{360^\circ} \sin\alpha \qquad (3.8)$$

where,

b_0 is the inlet width, R_1 the radius or diameter $D = 2R_1$ the runner, ϕ° is the admission arc angle, H is the net head, $\sin\alpha$ is the sin of the absolute velocity angle at the entrance to the runner.

Peripheral speed of the runner

$$u = K_u \sqrt{2gH} \qquad (3.9)$$

Where K_u is speed ratio, $0.45<K_u<0.48$

Runner diameter for given RPM

$$D = \frac{K_c}{N\sqrt{H}} \qquad (3.10)$$

CHAPTER-4

DESIGN AND DEVELOPMENT OF PROPOSED SYSTEM

4.1 GENERAL

A modified cross flow runner provided with guide tube is designed and fabricated. This chapter presents the details of the details of the design and fabrication of the runner.

4.2 DESIGN OF THE RUNNER

The procedural steps for the design of the cross flow turbine of the given data are as under give below;

Diameter of the runner = 200 mm

i.e. R_1 = 100 mm

And R_2 = $0.57\,R_1$ = 57 mm

For determining blade geometry other parameters required are calculated as;

$$C = \sqrt{R_1^2 + R_2^2 - 2R_1R_2\cos(\beta_1 + \beta_2)} \tag{4.1}$$

Taking $\beta_1 = 30^\circ$ and $\beta_2 = 90^\circ$

$$\therefore \quad C = \sqrt{100^2 + 57^2 - 2*100*57\cos(30+90)} = 137.65 \text{ mm}$$

$$\varepsilon = Sin^{-1}\left[\frac{R_2\sin(\beta_1+\beta_2)}{C}\right] \tag{4.2}$$

$$= Sin^{-1}\left[\frac{57\sin(30+90)}{137.65}\right]$$

$$= 21.0^\circ$$

$$\xi = 180 - (\beta_1 + \beta_2 + \varepsilon) \tag{4.3}$$

$$= 180 - (30+90+21.00)$$

$$= 39.0^0$$

$$\phi = \beta_1 + \beta_2 - (180 - 2\xi) \tag{4.4}$$

$$= 30+90-(180-2*39.0)$$

$$= 18.0^0$$

$$d = \frac{R_1\sin\phi}{2\sin(180-\xi)} \tag{4.5}$$

$$= \frac{100\sin 18}{2\sin(180-39)}$$

= 24.55 mm

$$\delta = 180 - 2(\beta_1 + \varepsilon) \tag{4.6}$$

= 180-2(30+21)

= 78.0^0

$$r_b = \frac{d}{\cos(\beta_1 + \varepsilon)} \tag{4.7}$$

$$= \frac{24.55}{\cos(30+21)}$$

= 39.0 mm

$$r_p = \sqrt{r_b^2 + R_1^2 - 2r_b R_1 \cos\beta_1} \tag{4.8}$$

$$= \sqrt{39^2 + 100^2 - 2*39*100*\cos 30}$$

= 69.03 mm

Flow admission area;

$$A = b_o L \tag{4.9}$$

Where, b_o is the inlet width

L is the admission arc length

$$L = \frac{2R_1\pi\phi}{360°} \tag{4.10}$$

$$= \frac{2*0.100*\pi*90}{360°}$$

= 0.157 m

$$A = \frac{Q}{C_m} \tag{4.11}$$

Where, Q is taken as 0.09 cumec for 4.5 kW output under 14.4 m head.

And $C_m = \sqrt{2gH}\sin\alpha$ (4.12)

$$= \sqrt{2*9.81*14.4}\sin 16$$

= 4.64 m/s

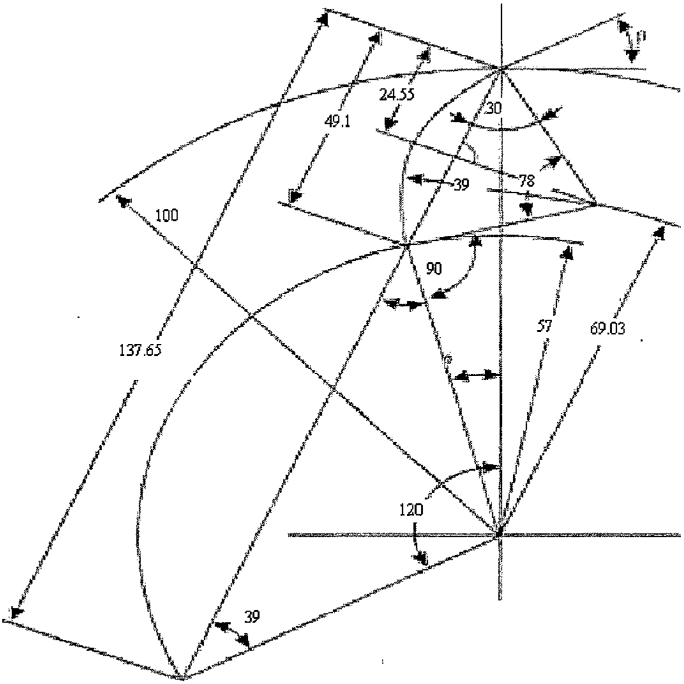
and, $A = \frac{Q}{C_m} = \frac{0.09}{4.64}$

= 0.02 m^2

$$b_o = \frac{A}{L} = \frac{0.02}{0.157} \tag{4.13}$$

= 0.127 m

No. of blades in runner = 27



(All dimensions are in mm and angles in degrees)

Fig 4.1: Geometry of Blade of Cross Flow Turbine (actual)

Table 4.1: Different parameters of cross flow turbine runner

S. No.	Parameters	Details
1	Diameter of the runner	200 mm
2	Outer radius of the runner, R_1	100 mm
3	Inner radius of the runner, R_2	57 mm
4	Outer blade angle, β_1	30^0
5	Inner blade angle	90^0
6	Curvature radius of the blade, r_b	39 mm

7	Pitch circle radius, r_p	69.03 mm
8	Segment angle of the blade, δ	78^0
9	Length of runner	127 mm
10	No. of blades	27

4.3 Design of Guide Tube

4.3.1 Guide Tube

The interior guide tube is the device which guides the flow for the second stage in flowing across the runner. The shape of guide tube is of aerofoil shaped. It is located inside the runner at the hollow space of the runner. The length of guide tube will be almost equal to the length of runner and width will be somewhat more than the space between shaft and the blades. The length and width of guide tub are shown in Fig.4.2.

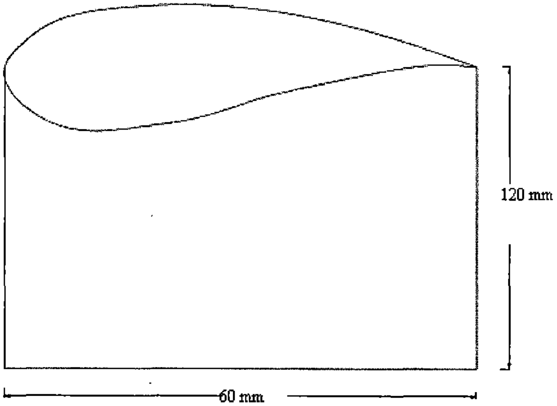


Fig 4.2: Guide tube

The cross sectional view of guide tube is shown in Fig.4.3

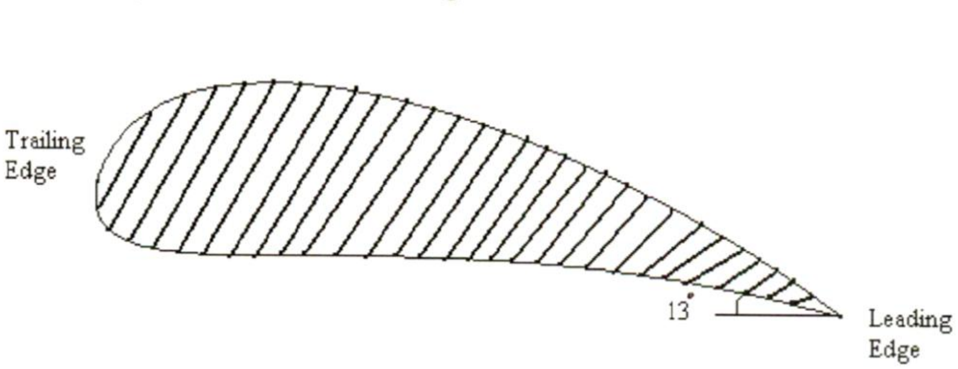


Fig 4.3: Cross sectional view of guide tube

The actual guide tube is shown in the Fig.4.4.

Fig.4.4: Actual guide tube

4.4 Mounting System of Guide Tube

The guide tube is mounted inside the runner with the help of shaft like support. The runner is mounted with the help of bearings. The interior guide tube is fixed inside the runner in the hollow space among the blades while the runner is free to move. There was no shaft in the runner and however there is a shaft inside the main runner shaft as shown in the Fig. 4.5

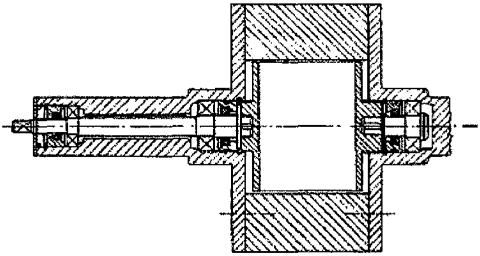


Fig.4.5 View of runner without shaft[17]

The discs with the shafts were bolted together with the runners. The shafts were mounted between two ball bearings. The interior guide tube is connected to the inside shafts by means of daggers. In this way, when the main shaft rotates with the runner, the shaft of the interior guide tube remains in no move. The position of the interior guide tube inside the runner can be fixed at any angle between 0 +/- 20^0 as shown in the fig.4.6.

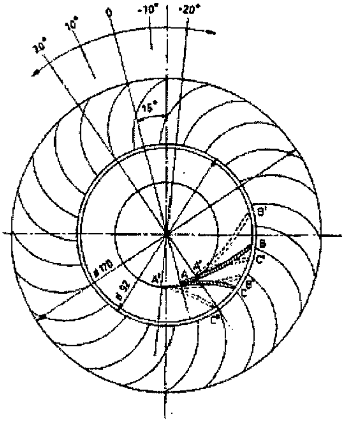


Fig.4.6: Location of guide tube [17]

The cross sectional view and the isometric view of the actual runner are shown in Fig 4.7 and 4.8 respectively.

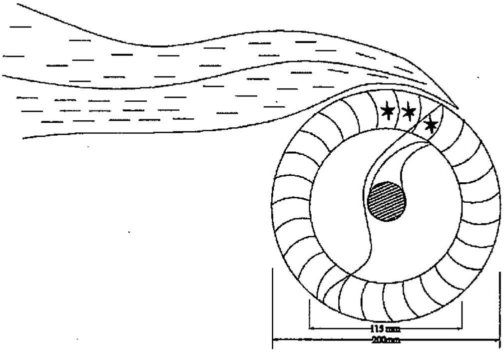


Fig.4.7: Cross-sectional View of Runner

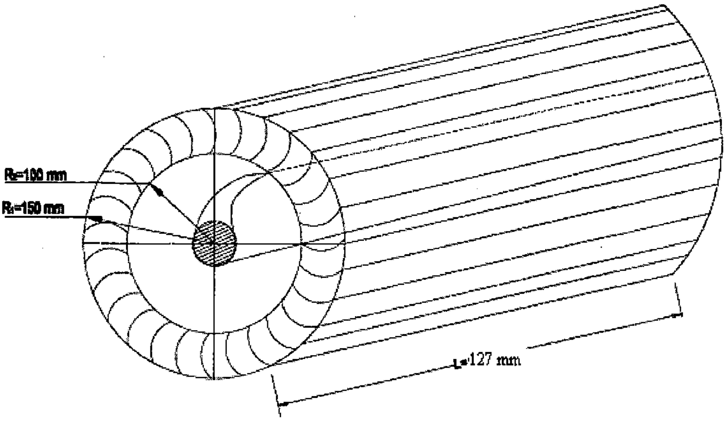


Fig.4.8: Isometric View of Runner

The runner with guide tube is shown in the Fig.4.9.

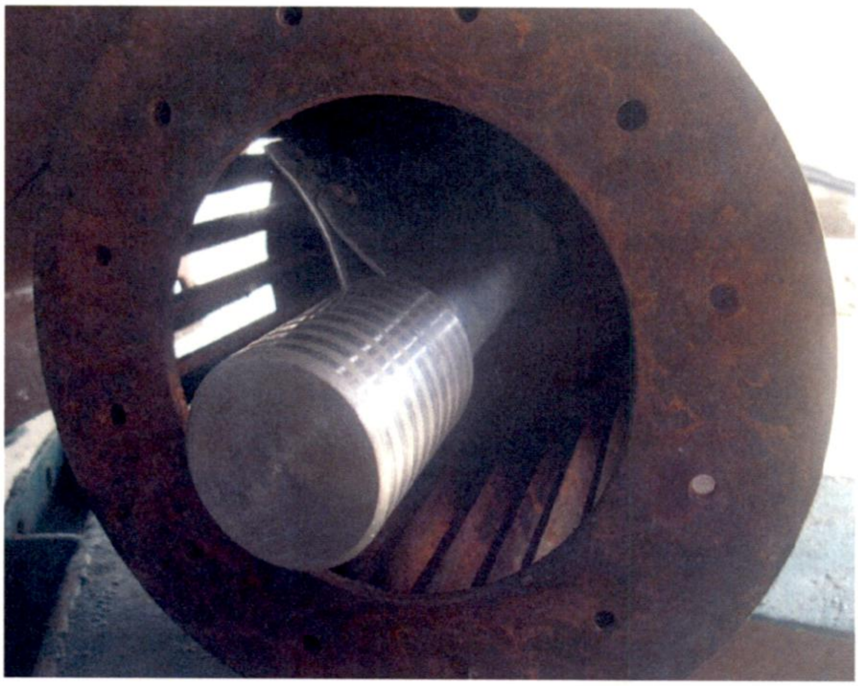


Fig.4.9: Runner with Guide Tube

The full assembly of the interior guide tube with the runner is shown in Fig.4.9.

CHAPTER-5

EXPERIMENTATION

5.1 GENERAL

In order to find the performance of a cross flow turbine experimental study has been carried out. For the improvement in the performance of cross flow turbine modification in runner has been made as discussed in chapter 4. The turbine is fabricated according to given data and is tested at a test rig at Alternate Hydro Energy Centre (A.H.E.C.), IIT Roorkee. In this chapter experimental investigations of cross flow turbine before and after modification to be carried out and the performance curves are prepared for each case are presented.

5.2 EXPERIMENTAL SETUP

A semi-closed loop-testing rig has been used for testing the cross flow turbine with interior guide tube. The testing rig consists of two service pumps of mixed flow type for pumping water at high pressure for providing the necessary head and flow. The specifications of the mixed flow pump used as turbine are given in Table 5.1. The two mixed flow pumps have been connected to the sump tank. From the sump the water supplied with high pressure in the cross flow turbine. After imparting motion to the same turbine. Water goes back through the channel to the same tank, from which the two mixed flow pumps again pump the same water back to the cross flow turbine. A digital pressure gauge has been connected to measure the head. An ultrasonic flow meter is used to measure the flow. A schematic diagram of the testing rig has been shown in Fig. 5.1 and Fig.5.2 shows the photograph of the test rig fitted with the turbine and generator.

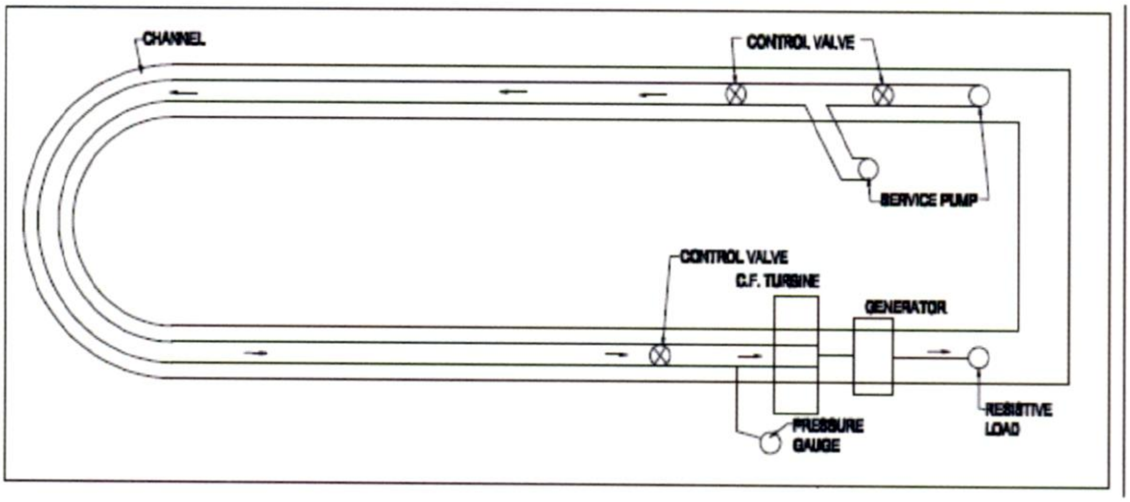


Fig. 5.1: **Schematic Diagram of Test Rig and Experimental Setup**

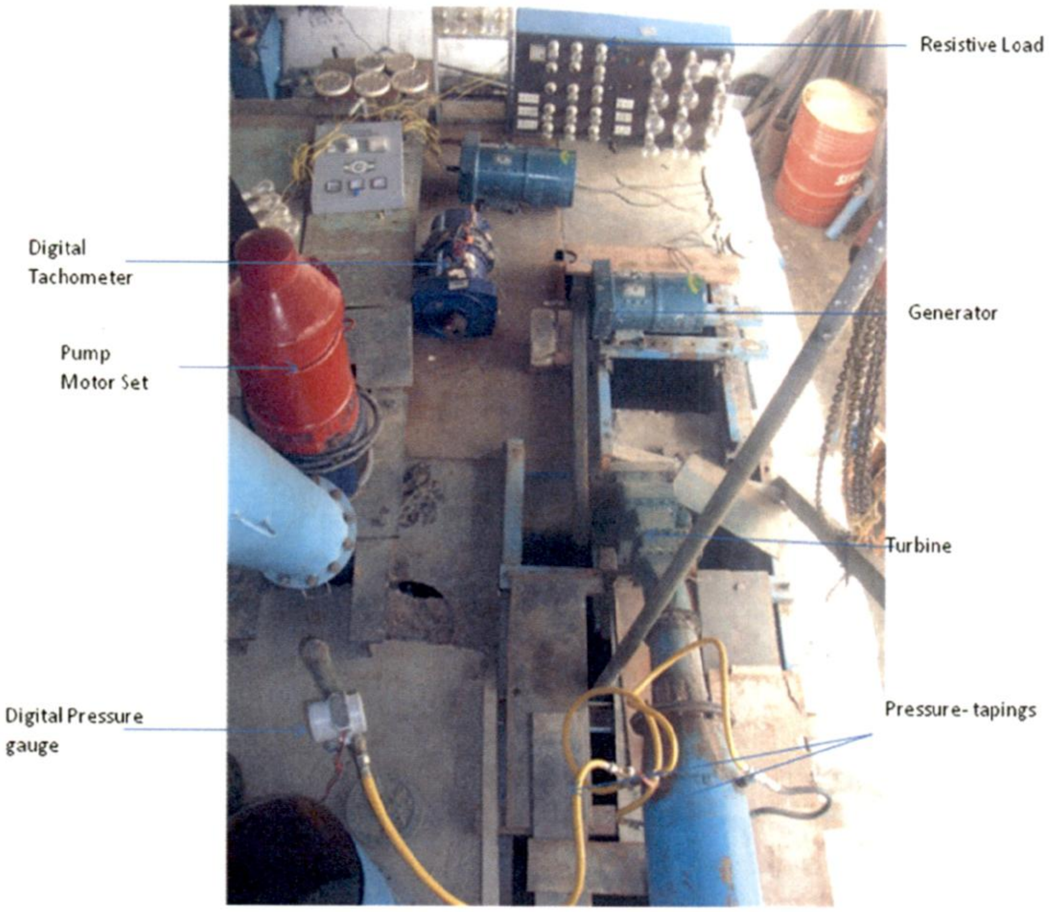


Fig 5.2: **View of the Test Rig and Experimental Setup at AHEC IIT Roorkee**

The runner with guide tube along with the nozzle is shown in Fig.5.3at the test rig.

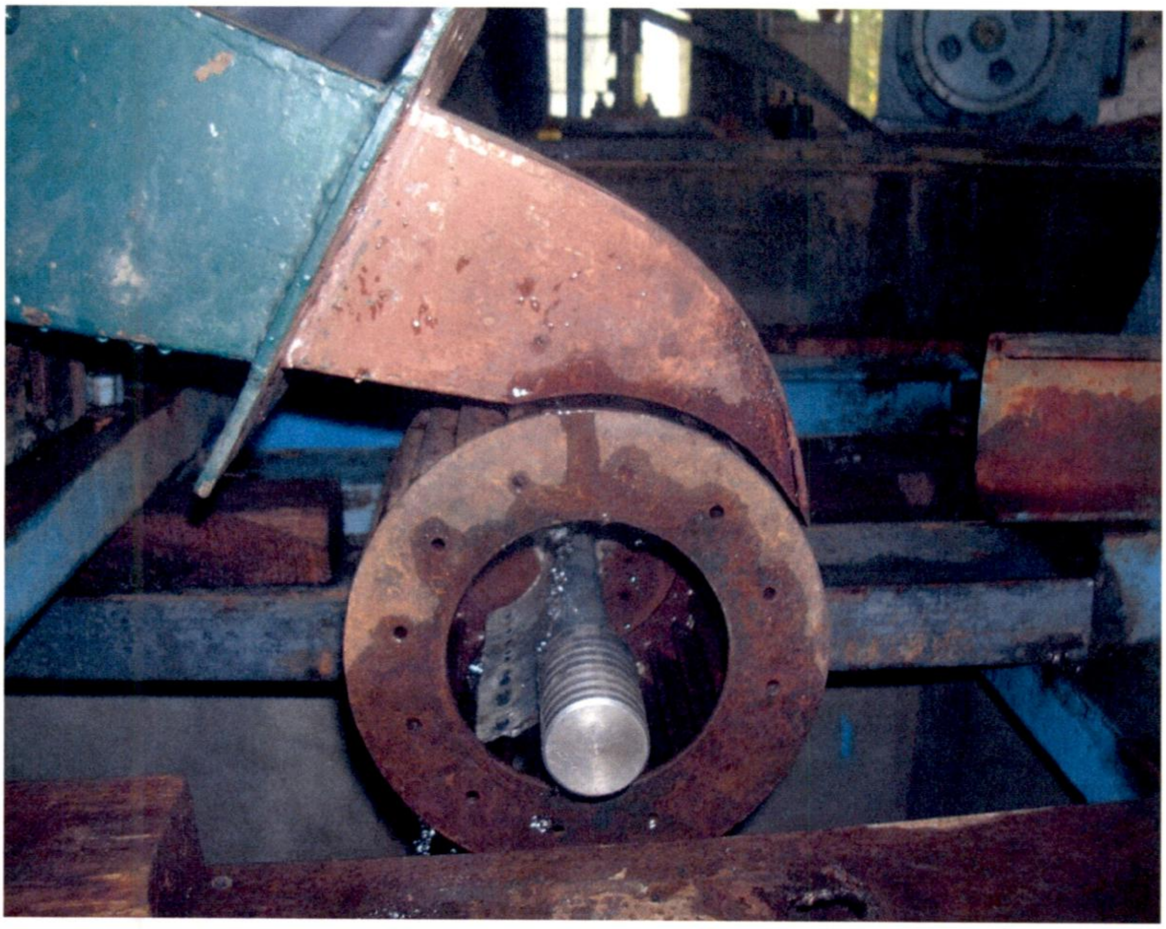


Fig: 5.3: View of runner with guide tube along with the nozzle

The full assembly of the cross flow turbine at the test rig is shown in Fi.5.4The fig shows the fixed guide tube at the mild steel angle frame while the runner is free to move.

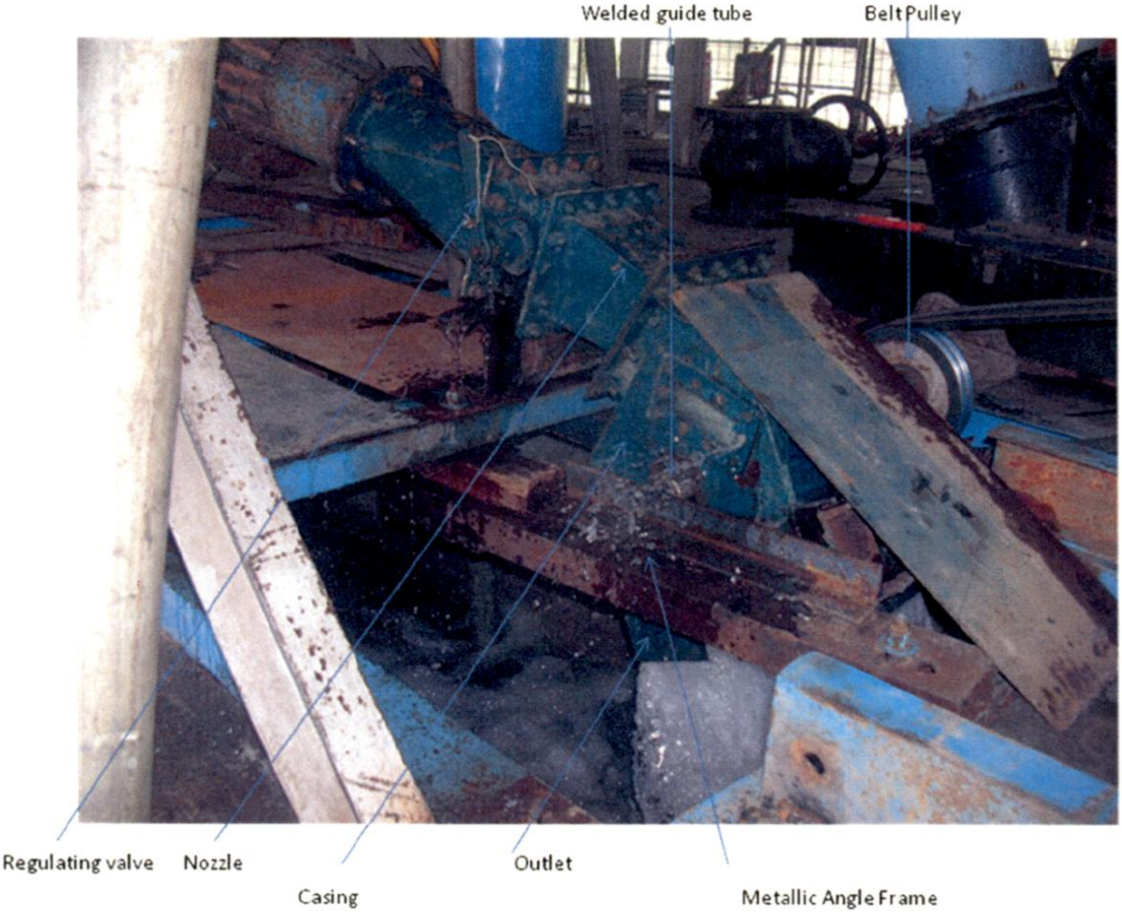


Fig: 5.4 View of full assembly of cross flow turbine at test rig

5.3 RANGE OF PARAMETERS MEASURED

The specification of the mixed flow pump has been shown in Table 5.1. Parameters, which have been measured, are given in Table 5.2 with their operating ranges for the pump used as turbine before modification.

Table 5.1 Specification of a Service Pump of Test Rig

S. No.	Parameters	Details
1	Make	M/S HSMITC, Karnal
2	Type	Mixed Flow, Vertical Shaft
3	Head	10 m

4	Discharge	150 lps
5	Motor	22.5 kW

Table 5.2: Salient features of cross flow turbine considered for present study

Rated Head	14.5 m
Rated Discharge	0.09 m^3/s
Rated Turbine Output	3.77 kW
Rated Speed	1500 rpm
No. of Runner blades	27
Outer diameter of runner	200 mm
Inner to outer diameter ratio	0.57
Runner length	127 mm

5.4 INSTRUMENTATIONS

During the investigations and experiment various parameters have been measured. Different instruments are used for measuring those parameters are discussed below.

5.4.1 Head

Head has been measured using an digital pressure gauge, LD301 (pressure gauge). Fig. 5.5 shows a view of LD301 while taking a reading during conducting the experiments.

Fig. 5.5: Intelligent Pressure Transmitter, LD301 used for Measuring Head in atmosphere

5.4.2 Discharge

The ultrasonic transit time flow meter is very precise instrument which directly gives the reading of the discharge in cumec or lit/s. In the instrument two ultrasonic transducers are connected one for upstream flow and another for downstream. The upstream transducer is of red in color for identification while the downstream of blue in color. The flow meter automatically calculates the distance between the transducers for flow measurement according to the outer diameter of the pipe, internal diameter of the pipe and the material of the pipe. The beauty of this instrument is that there is no need to drill the pipe for flow measurement and the setting of transducers needed only some open portion of the penstock. The fig.5.6 shows the measuring of the UTTF instrument.

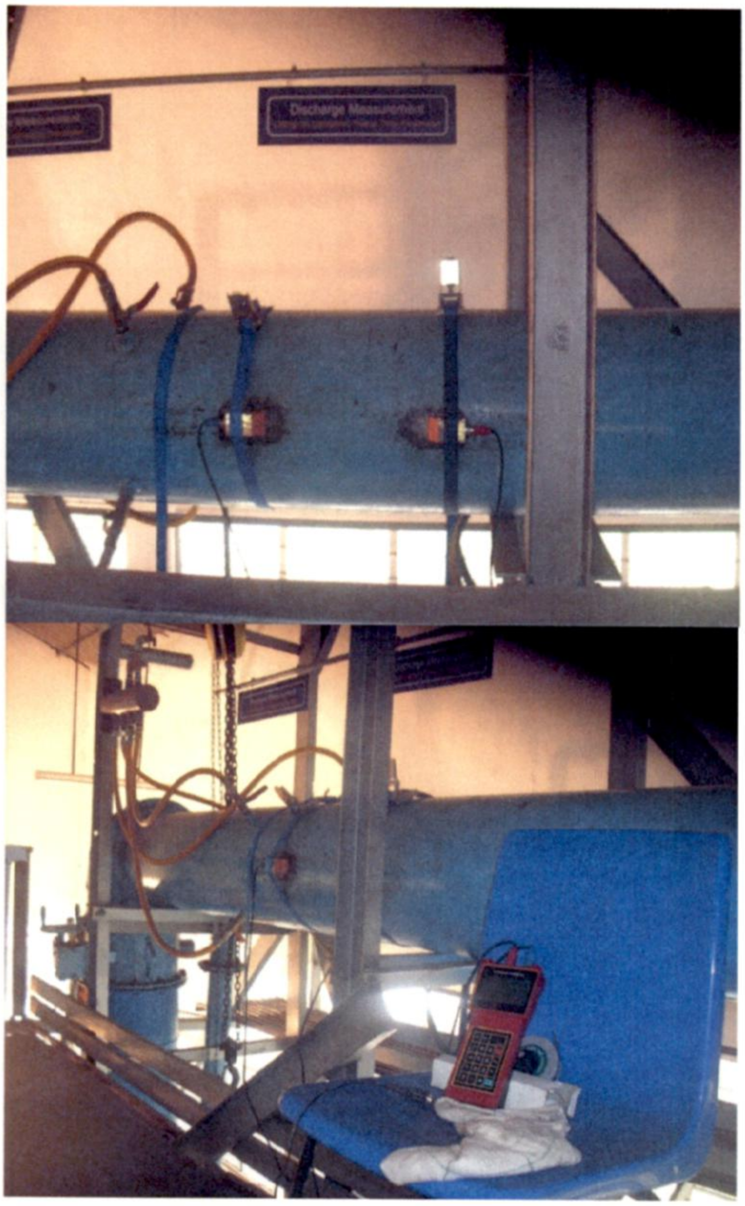


Fig. 5.6: R.R. Ultrasonic Transit Time Flow meter with clamping on the Pipe

5.4.2 RPM of Turbine and Generator

Speed of turbine and generator was measured by using digital R.P.M. indicator. Fig 5.7 shows the view of digital rpm indicator while taking a reading during conducting the experiment.

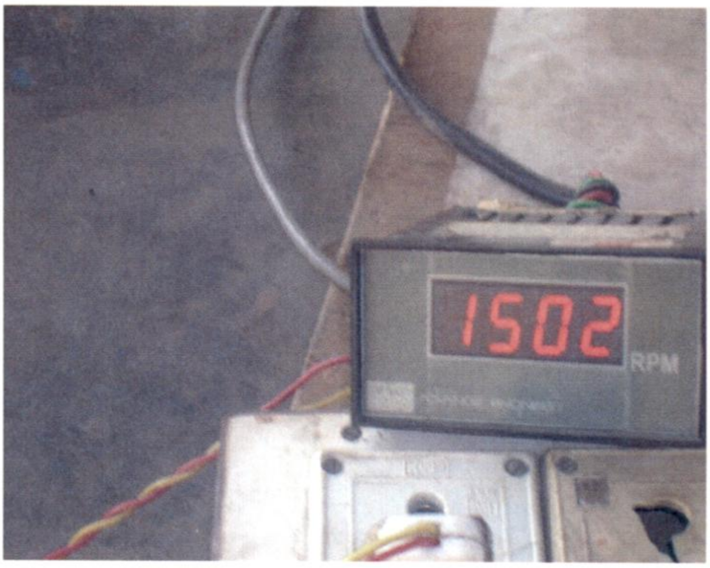


Fig 5.7: Speed (R.P.M.) Indicator

5.4.3 Resistive Load and Watt meter

The load on the generator was put as resistive load using 100 W, 200 W and 500W bulbs fitted in a panel, as shown in Fig. 5.8. Watt meter is used to measure the power generated by the generator connected with cross flow turbine as shown in Fig 5.6.

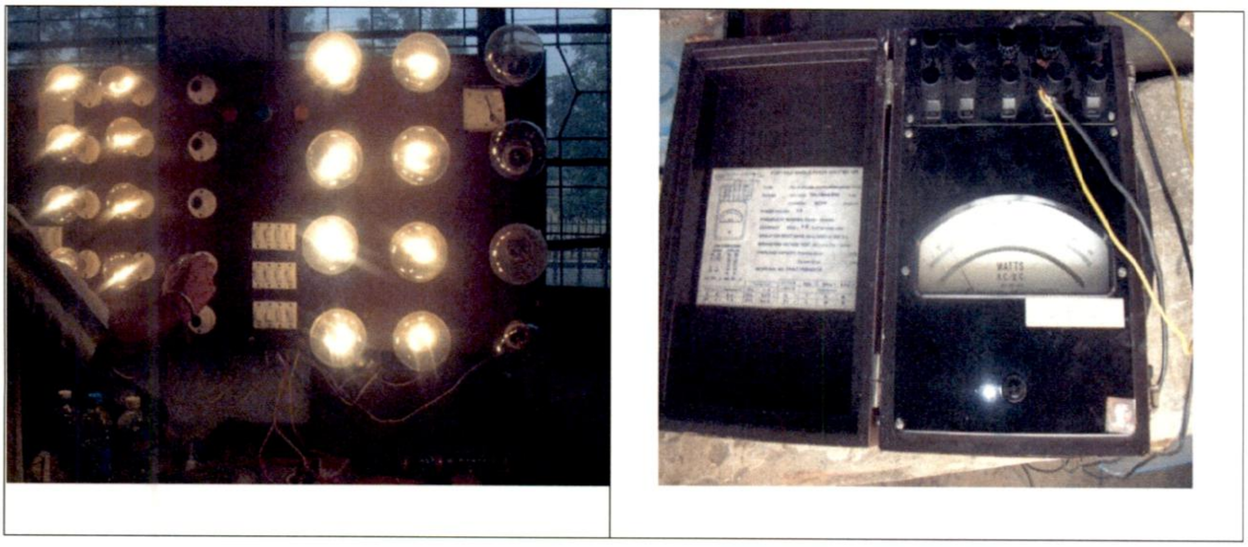


Fig. 5.8: Resistive Load and watt meter

5.4.4 Power Output

A 3-phase synchronous generator is used in testing, as shown in Fig.5.9.

Fig 5.9: View of AC Generator used for the Experiment

5.5 EXPERIMENTAL PROCEDURE

The cross flow turbine was tested without guide tube was tested at the rig without modification. Two service pumps have provided in the sump tank which supply the required flow for the operation of cross flow turbine. The main inlet valve was at the turbine inlet to vary the discharge supplying to the turbine. A digital pressure gauge was connected to the turbine inlet for measuring the pressure head. For the discharge measurement ultrasonic transit time flow meter was used, which was fitted on the pipe supplying the discharge. The turbine was connected to a synchronous generator through a belt and pulley arrangement. The generator was connected to the panel having bulb loads and a wattmeter for measuring the generator output. Slowly the valve was opened and the water was made to flow through the turbine runner. After that the valve was opened and the turbine started to rotate with more speed. Then the load on the generator was given by switching on the bulbs. The flow and the bulb loads were so adjusted as to maintain 1500 rpm of the generator. The reading of the pressure gauge (head), ultrasonic transit time flow meter (discharge), bulb loads, and wattmeter were noted. After that valve was opened further more and again the procedure was repeated and several readings for varying discharge were taken given in the tables as given below.

5.6 PARAMETERS OBTAINED DURING TESTING

5.6.1 Head

The head, *H* acting on the cross flow turbine has been calculated using the turbine inlet pressure. The turbine inlet pressure is obtained in terms of atmospheres. It has been converted into meters of head of water by multiplying it by ten.

$$H = 10P_i \tag{5.1}$$

Where H is the head in meters and P_i is the turbine inlet pressure in atmospheres.

5.6.2 Discharge

The ultrasonic transducers are clamped with the help of ribbons to the pipes for precise results so that the vibrations do not affect the readings of the discharge. The clamps are tight optimally with help of specially designed clamps and ribbons. The Fig.5.4 shows the clamps setting on the pipe for discharge measurement. The flow meter gives the reading directly in cumec or lit/s.

5.6.3 Power Input

Cross Flow Turbine input, T_i has been obtained using the following formula:

$$Ti = Q\, g\, H \;\; kW \tag{5.2}$$

Where Q is the discharge in m^3/s, H is head in m and g is equal to $9.8\ m/s^2$.

5.6.4 Cross Flow Turbine Output

Cross flow turbine output, T_o has been obtained by the resistive load added to the testing time and maintaining the turbine and generator RPM constant i.e. 1500.

5.6.5 Cross Flow Turbine Efficiency

Efficiency, η_{CFT} of Pat has been calculated using the following formula:

$$\eta_{CFT} = \frac{T_o}{T_i}$$

Where, T_O and T_i are turbine output and input respectively.

5.7 EXPERIMENTAL INVESTIGATIONS OF CROSS FLOW TURBINE WUITHOUT GUIDE TUBE

Cross Flow Turbine has been tested on the test rig before modifications. Different data are collected during the testing at different flows and constant speed, which defines the performance of cross flow turbine. These collected data during experiment are shown in Table 5.3. Fig 5.10 shows the curve for head versus efficiency of cross flow turbine before modification. Maximum head available at turbine inlet is 14.45 m. The maximum efficiency has been obtained corresponding to 14.45 m head and 0.09 cumec discharge. Fig 5.11 shows curve for discharge versus efficiency of cross flow turbine before Modification. It has been found that the maximum efficiency obtained 32.94% corresponding to 14.15 m head and 0.09 cumec discharge.

Table [5.3]: Data for Cross Flow Turbine before Modification

WITHOUT GUIDE TUBE						
S.No.	**Head (m)**	**Flow (cumec)**	**Power input (kW)**	**R.P.M.**	**Power output (kW**	**Efficiency (%)**
1	8.3	0.058	4.72	1500	0	0
2	8.65	0.052	4.41	1500	0.46	12.26
3	10.05	0.061	6.02	1500	0.96	18.78
4	11.35	0.072	8.02	1500	1.76	25.83
5	11.95	0.079	9.26	1500	2.25	28.58
6	13.65	0.09	12.05	1500	3.25	31.73
7	14.45	0.095	13.46	1500	3.77	32.94

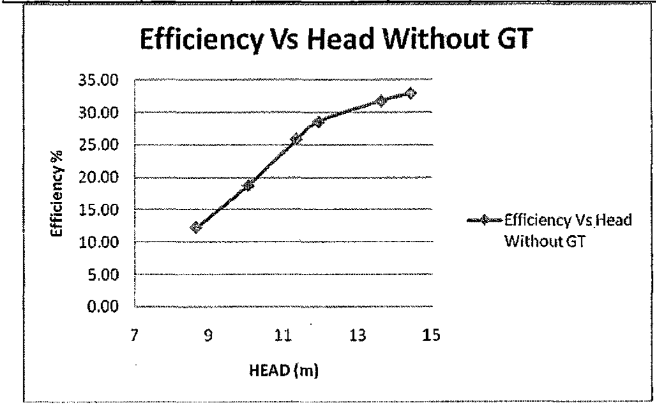


Fig 5.10: Curve for head versus efficiency of Cross Flow Turbine before Modification

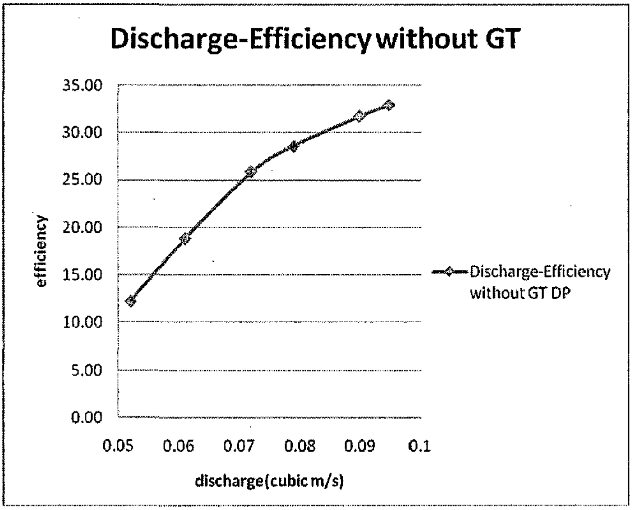


Fig 5.11: Curve for discharge versus efficiency of Cross Flow Turbine before Modification

5.8 EXPERIMENTAL INVESTIGATIONS OF CROSS FLOW TURBINE WITH GUIDE TUBE

After providing the modification in the cross flow turbine by installing the guide tube, turbine has been tested on the test rig at different flows and constant rpm. Table 5.4 shows the data taken during the testing of turbine after installing the guide tube. Fig 5.12 shows the curve for head versus efficiency of Turbine after installing guide tube. Maximum head available at turbine inlet is 14.45 m. The maximum efficiency has been obtained corresponding to 14.45 m head and 0.09 cumec discharge. Fig 5.13 shows curve for efficiency versus discharge of Cross flow Turbine after installing guide tube. Maximum power generated through the Turbine is 4.5 kW. It has been found that the maximum efficiency obtained 40 % corresponding to 14.45 m head and 0.09 cumec discharge.

Table [5.4]: Data for Cross Flow Turbine after Modification

WITH GUIDE TUBE						
S.No.	**Head (m)**	**Flow (cumec)**	**Power input (kW)**	**R.P.M.**	**Power output (kW**	**Efficiency (%)**
1	7.65	0.05	3.75	1500	0	0
2	8.65	0.05	4.24	1500	0.64	17.75
3	10.05	0.061	6.02	1500	1.277	24.98
4	11.35	0.075	8.35	1500	2.36	33.25
5	11.95	0.079	9.26	1500	2.76	35.06
6	13.65	0.09	12.05	1500	3.98	38.85
7	14.45	0.094	13.32	1500	4.53	40.00

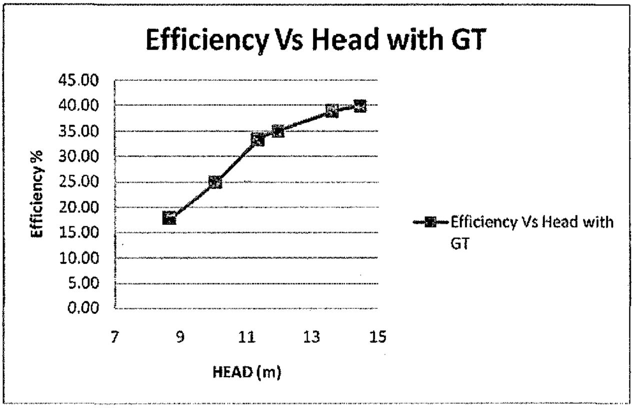


Fig 5.12: Curve for Head versus Efficiency of Cross Flow Turbine after modification

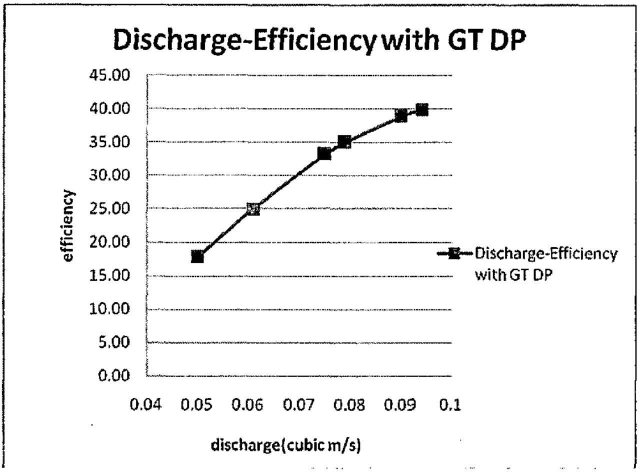


Fig 5.13: Curve for Discharge versus Efficiency of Cross Flow Turbine after modification

5.10 COMPARISON OF THE PERFORMANCE

Fig 5.14 shows the comparison of variation in efficiency of cross flow turbine before and after modification with head. At the full opening of valve 14.45 m head has obtained for maximum flow 0.09 cumec. Fig 5.14 shows the comparison of efficiency with change in head of cross flow turbine before and after installation of guide tube. Fig 5.15 shows the comparison of efficiency with change in discharge of cross flow turbine before and after installation of guide tube. When the water goes across the shaft for the second stage to strike the blades of turbine it is unguided. Therefore, the modification in turbine is done by installing guide tube in the runner to guide the water for the second stage. The interior guide tube is of aerofoil shaped because aerofoil shape offers least friction. It has been observed from this comparison study that 7.06 % improvement in the peak efficiency of Cross flow Turbine at 1500 r.p.m. can be achieved for the wider ranges of flow. The optimum positions of the guide tube inside the runner can be fixed at any angle between 0 +/_ 20^0.

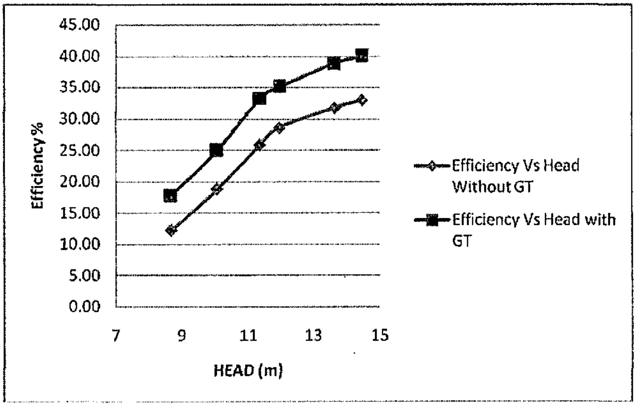


Fig 5.14: Curve for comparison of turbine efficiency versus head between with and without guide tube

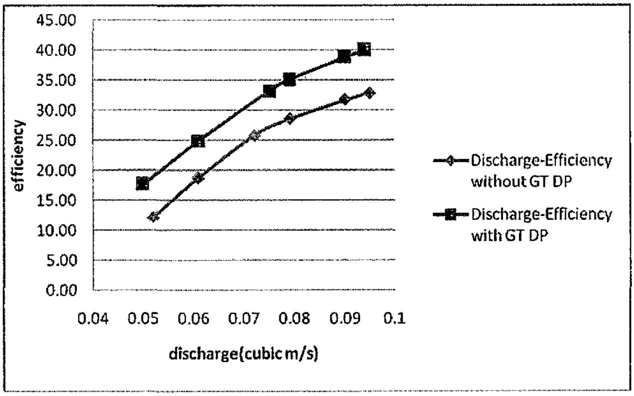


Fig 5.15: Curve for comparison of turbine efficiency versus discharge between with and

CHAPTER -6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

In the micro hydro range cost is more important than the efficiency of machine due to the low capacity of plant. In this dissertation an attempt has been made to improve the efficiency of cross flow turbine to increase its utility with optimum peak efficiency. Following conclusions has been made from the present work of dissertation:

(i) A cross flow turbine runner is fabricated for the given site data as; head 14.5 m; discharge 0.09 cumec; speed:1500 r.p.m for the present investigation.

(ii) The blade geometry of the runner is designed according to given data and found as; curvature radius of blade is 39.0 mm, pitch circle radius of blade is 69.03 mm, length of runner is 127 mm, no. of blades in runner are 27.

(iii) A modification has been made to improve the peak efficiency of cross flow turbine by installing guide tube in the runner. The characteristic curves have been drawn from the data obtained by testing. About 7.06% improvement has been found in the peak efficiency.

(iv) Testing of Cross Flow Turbine has been done without modification and after modifications and data have been collected. Performance characteristics for different cases have been discussed.

(v) It has been observed that the peak efficiency of Cross Flow Turbine after modification has increased by 7.06%.

(vi) The shape of guide tube is aerofoil. The length of guide tube is 120 mm and width is 60 mm.

6.2 FUTURE SCOPE

(i) Optimum position of guide tube is required to be analyzed.

(ii) To improve further the efficiency of cross flow turbine a draft tube may be used for performance analysis in future study.

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2. Imran Khan, R.P.Saini, and S.K.Singal "Modification in cross flow turbine for improveing efficiency" 'International Conference on Energy and sustainable development: issues and strategies' Asia Institute of Technology, Bangkok, Thailand, abstract selected.