EFFICIENCY IMPROVEMENT OF MICRO HYDEL TURBINE THROUGH MANUFACTURING TECHNIQUES

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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MASTER OF TECHNOLOGY

in

ALTERNATE HYDRO ENERGY SYSTEMS

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is presented in this dissertation entitled, **"EFFICIENCY IMPROVEMENT OF MICRO HYDEL TURBINE THROUGH MANUFACTURING TECHNIQUES"**, in partial fulfillment of the requirement for the award of the degree of **Master 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 2005 to June 2006 under the supervisions of **Dr. R.P. Saini**, Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee and **Shri S.K. Singal**, Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee.

The matter embodied in the dissertation has not been submitted by me for award of any other degree.

Date: June 30, 2006

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CERTIFICATE

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ABSTRACT

Micro hydropower typically stand-alone system in the range of 1-100 kW has been proved useful in powering remote domestic loads. The utilization of micro hydro electricity for small-scale industry and productive processes can often reduce the payback period on capital investment from over 20 years to less than five years. However, such potential exploitation may not be economically viable as the capacity of hydro power plant decreases, the generating cost per unit increases. Hence to make it economically more viable, the methodology and technology applied must be different from that applied to larger capacity hydro plant.

The hydrological potential for micro-hydro is such that the possible sites tend to be low in output power, large in number, and widely dispersed. The concept of micro-hydro is thus found to be appropriate to the hilly areas in Himalayan region in the Indian context.

The problem associated with small hydropower exploitation especially in micro hydro is technical as well as economical. Each proposed site requires individual considerations for civil works as well as for electromechanical equipment. Therefore, costs become infeasible due to lack of standardization of the system for such a small power generation. From past experiences it is observed that the exploitation of micro hydro potential has not been the successful story due to application of scale down approach for civil works and non-standardization of equipment. This leads micro hydro power plants uneconomical. Keeping this in view, it is felt that there is a need to find out cost-effective strategies for the development of micro hydropower.

In the present study hydro turbines that are suitable for micro hydro range (Capacity less than 30 kW) has been discussed, due to non-availability of standard manufacturers of turbines of low capacity. The unit cost of turbine is high and this affects the overall cost of the project. This may be due to non-standardized nature of the site parameters in this range, lack of standardized design of equipments. In view of this, various approaches of manufacturing of micro hydro turbines for the micro hydro power plants have been discussed and their application for the turbines sites are in this range is also given. It is found that Pelton, Cross flow, Turgo impulse and Pump as turbine are best suited for this range. The manufacturing processes and possible materials required to manufacture the turbines are discussed in detail. A cost analysis for manufacturing process suitable in this range of hydro turbine is also carried out. Various parts have been identified which have the effect on efficiency as well as cost, are discussed in detail. Effect of surface roughness of turbine parts has been found the critical parameter, which effects turbine efficiency and cost of turbine. An empirical relation has been developed between surface roughness and efficiency of turbine, which could be beneficial to provide a guideline to the local manufacturers.

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NOMENCLATURE

Q = water flow rate for turbine

H = net head for turbine

N_s = specific speed

N = turbine speed

P = power

V = velocity of jet

k_v = coefficient of velocity

g = acceleration due to gravity

d = diameter of nozzle

u = circumferential velocity of bucket

T = torque transmitted

D = hub diameter

α = angle of spear

β = angle of nozzle

d_0 = diameter of nozzle

d_i = least diameter of jet

η = efficiency of a turbine

P_t = power developed by turbine including all losses

P_a = actual power available

η_{vol} = volumetric efficiency

η_h = hydraulic efficiency

P_M = mechanical losses

k	= coefficient for friction losses in bucket
K_{u1}, K_{v1}	= coefficient of velocity in nozzle for Pelton turbine
C	= coefficient of velocity in nozzle for cross flow turbine
Φ	= coefficient of velocity in cross flow turbine
b_0	= width of nozzle for cross flow turbine
R_1	= outer radius of cross flow turbine runner
R_2	= inner radius of cross flow turbine runner
β_1, β_2	= blade angles for cross flow turbine

INTORDUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Energy plays a significant role in the economic and technological advancement of modern society. It is a vital input in all development activities. The more appropriate and relatively modern energy systems are needed to meet the ever-increasing demand of electricity.

Hydropower is most promising among the renewable energy resources. It is a clean source of power produced when water turns a hydraulic turbine. It provides the electricity essential to economic and social development. Although in the latter part of the nineteenth century many small hydroelectric plants were in operation, the trend in the twentieth century has been to develop large-scale systems.

Hydro power is probably the most oldest and yet the most reliable source of all renewable energy, with bulk of its potential yet to be harnessed in many countries. Though hydro power development started with small units of 100 kW in the beginning, attention was diverted to harnessing medium and major hydro because of their comparative economics. India has a large potential of hydro energy in medium and big projects. After independence large hydroelectric projects have been executed, with some of them are still under construction and some have been planted for future. The inherent drawbacks associated with large hydro are; large gestation period, large area along with vegetation has to be submerged, shifting people etc from the sites. Political and environmental implications have made planners to think for some other alternative to these large hydro and thus comes the concept of small hydro. There is general tendency all over the world to define small hydro by power output. The plant capacity limit range for different countries is given in Table 1.1.

In India development of small hydro power has been taking place since its first hydro installation of 130 kW at Darjeeling in the year 1897. An estimated potential of 1500 MW of small hydro exists in India. However, nearly 12015 MW have been actually identified through 4703 sites. In Himalayan and sun Himalayan area of northern India, perennial streams with small discharges are available which can be harnessed for small hydro power generation. This type of power generation does not require water storage and use the concept of 'run of river' i.e. water is taken from running stream. The advantages of small hydro are low gestation period, low initial cost. No shifting of locals from their land, no loss to environment etc.

Table 1.1: Plant capacity limit range for different countries [1].

Country	Plant Capacity
U.K.	Up to 5 MW
Unido	Up to 10 MW
India	Up to 25 MW
Sweden	Up to 15 MW
Columbia	Up to 20 MW
Australia	Up to 20 MW
China	Up to 25 MW
Philippines	Up to 50 MW
New Zealand	Up to 50 MW

The term small hydro has wide range in usage, covering schemes having installed capacities from a few kW to 25 MW. In India small hydro schemes are further classified by Central Electricity authority (CEA)[2] and are given in Table 1.2

Table 1.2: Classification of small hydro schemes

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 25,000 kW	1001 to 5,000 kW

1.2 Importance of micro hydropower

The power potential of 18790 MW is available in micro hydro range and it is going to ready for harnesses immediately. The current concern on the global environment has imposed a new restrain on the production of electricity. The emphasis is put on the development of environmental friendly energies to promote the sustainable social development. It is in these circumstances, the micro hydro power is drawing more

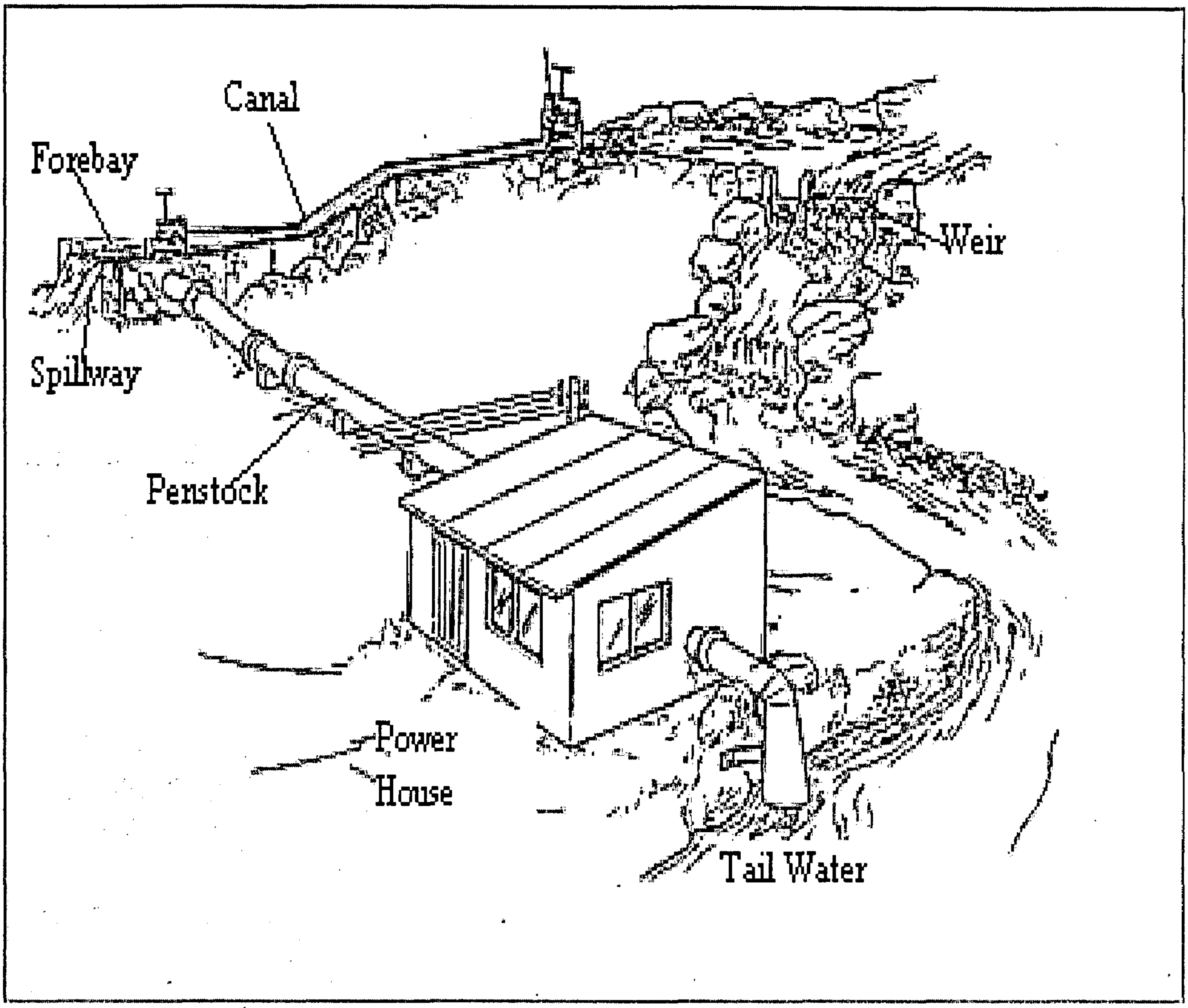


Fig 1.1: Layout of typical SHP station

attention. A rural population is scattered, poor and unaware of technological progress. For such areas, the isolated micro-hydro power plants are usually the least-cost option. This is mainly because other options for supply of energy 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 region, micro-hydro power plants can easily meet the energy 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 other small scale industries. This use of electricity in the form of heat can contribute significantly towards reducing the burning of wood and other biomass, which has many derogatory implications in terms of environment and health. In addition to meeting the needs of an area, a properly designed, installed and managed micro-hydro power plant can also contribute significantly towards employment generation, improved living conditions and improved education facilities.

The Chinese experience shows that micro hydro power schemes could be taken as a sustainable rural energy source. The following reasons can be made in support of the above statement [3].

- It enables the coordination between hydropower development, sustainable economic development and environment protection. It can improve local environment once constructed and has comprehensive benefits in social, environmental and economic aspects. Micro hydro can meet the need of rural development today, while not affecting the future development.
- It replaces firewood with electricity and helps the establishment of a clean rural energy structure. To change the traditional way of cooking with firewood is a big reform in rural energy field. To replace firewood with electricity, to promote electric processing and cooking prove to be very effective in reducing deforestation and improving ecological environment.
- It will improve the rural ecological environment to take rural electrification construction as the focus, supplemented by comprehensive development of small river basins.

  Experience in some areas proves it is a very effective way in improving local ecological environment to undertake multi-purpose development with micro hydro power development, small river basin comprehensive treatment and soil preservation combined.

1.3 Constraints in development of micro hydro

The micro hydro schemes have not been successful in the recent times particularly in India. The following reasons can be attributed for this [4]:

i) The high initial capital cost of micro hydro schemes acts as an impediment to the expansion of hydropower, especially in the developing countries where the funding problems are most acute.

ii) Small capacity project lack the advantage of scale and their cost per kW can therefore is quite high.

iii) The micro hydropower can be a problem if an isolated hydro plant is required to meet the year-round demand for electricity. Such a situation requires backup support, leading to substantially increased operating costs and pollution associated with diesel or thermal generation.

iv) The output of micro hydro is critically dependent on the temporary water run-off and hence subject to the prevailing hydrological cycle.

v) The expertise available for operation and maintenance is generally poor.

vi) Most of micro hydro power plants are under their respective state electricity boards/nodal agencies, with their conventional approach of large hydro. Scale down approach of technology for micro hydro has not been economically viable.

vii) It has also been observed that micro hydel plants are non-operating in the area where already grid is available.

viii) In order to apply the standardize approach, reliable data for potential in this range are still not available.

The constraints related to micro hydro power development discussed above contribute the factor of high costs of the plant and make them economically non-viable.

1.4 COMPONENTS OF MICRO HYDRO POWER STATION.

The basic components of micro hydro station can be broadly classified into components of i) civil works and ii) Electro-Mechanical equipments. The various components of micro hydro power station are shown in Fig 1.1. They are discussed below;

1.4.1 Civil works

Civil works of micro hydro power schemes generally comprise of the following structures

1.4.1.1 Diversion weir and intake.

The purpose of diversion is to divert the water from main stream to power house via power channel. Diversion can be of temporary nature or permanent nature. For micro hydro schemes it is of temporary raised weir which is generally repaired every year. For schemes located in remote areas this option is appropriate and economical

1.4.1.2 Water conductor

It s purpose is to carry diverted water towards forebay tank. They are constructed by simply excavating the ground to required canal shape or second option is stone masonry in mud mortar.

1.4.1.3 Forebay tank

Forbay is constructed to connect the penstock with the power channel. Local materials can be used to construct it.

1.4.1.4 Penstock

Penstock carry the water from forebay tank to the turbines. Mild steel or HDPE pipes are most commonly used as penstock material. Penstock should be sufficient strong to withstand the water pressure.

1.4.1.5 Spilling arrangements

The excess flow that enters into the intake during the flood flows needs to be spilled as early as possible. This is achieved by incorporating a spillway close to the intake. If head race is long another spillway may be required along the canal section such that the entire design flow can be diverted if the canal is blocked due to falling debris from above or landslides.

1.4.1.6 Power house building

Power housing building comprises the turbine and generator assembly. Local materials can be used as far as possible.

1.4.1.7 Tail race channel

The water leaving turbine passes through tails race channel to meet the original stream. Its purpose is to restore the energy of water.

1.4.2 Electro-Mechanical Equipment

The electro mechanical equipment is considered to be the equipment and system required to develop the energy available in impound or flowing water to convert it into electrical energy, to control it and to transmit it to a regional power grid [5].

The major electro-mechanical component of power plant are the inlet valve, turbine, draft tube, gates, generators, control and protection equipment and substation for transformation of power to the transmission line voltage. In terms of space requirement and cost the major items are the turbine and generator. A standard for micro hydro developed by AHEC, IIT Roorkee discuss various aspects of micro hydro [6].

1.5 PRESENT STATUS OF MICRO HYDRO POWER STATIONS.

Experience of micro hydro power plants in India is not very encouraging as compared to other countries like Nepal and china. Though India has been the pioneering country in starting micro hydro power plants, but it couldn't keep the pace with time. Even the plants established could not give optimal results for long time. Based on the practical experiences reported in literature [7], status of the micro hydro plants are discussed as follows.

- Most of the micro hydro power plants are under their respective state electricity boards/nodal agencies, with their conventional approach of large hydro. Scale down approach of technology for micro hydro has not been economically viable.
- The operations of the plants could not be managed properly. Number of operators and their salaries could not be justified for such small power plants. However, part time operators were employed but even this could not be done properly. Mostly influential people got their candidate selected irrespective of their technical know-how. This lead to poor maintenance of the plant thus poor output and thus low revenue being collected from local people using power, and hence made the plant uneconomical.
- Small Hydro Power sites are not standardized, so no big manufacturers are interested in manufacturing of micro hydro turbines.
- The turbines used in micro hydro range are local manufactured. But local manufacturers are not having adequate facilities to manufacture these kinds of turbines and also they are not aware of any standard procedures. So the quality of final product is not up to the mark. So the quality, efficiency needs to be compromised.
- Because of poor maintenance occurrence of which turbine failure due to its misalignment with the generators results in bearing failure and finally shut down. Turbine failure also takes place due to reasons, like broken tips of the blades which is common problem associated with locally made cross-flow turbines reason being metal fatigue.
- It has also been observed that micro hydro power plants are non operating in the area where already grid is available.

As discussed earlier lots of potential is available in the range of micro hydro and is immediately ready to harnessed. It has been observed that micro hydro power development has not been a successful story in the past. The main problem associated with small hydro plant exploitation in the range of micro hydro (<100 kW) is its uneconomical operations and high initial cost. Major factors being relatively high cost of generating equipments i.e. turbine because of non standardization and locally made.

1.6 GOVERNMENT POLICIES FOR DEVELOPMENT OF MICRO HYDRO

As discussed above so much of potential is available in micro hydro range. To accelerate the development of micro hydro ministry of non conventional energy resources (MNES) providing following incentives [8]

- Detailed survey and investigation -- up to Rs 3 lakh per site
- Detailed project report preparation - up to Rs 2 lakh per project
- Interest subsidy for commercial projects - up to 7.5 per cent in the hilly regions and up to 5 per cent in the plains
- Under special incentives for the northeastern region and Sikkim, capital grant of up to Rs 7.5 crore per MW is available for SHP projects in the region. The maximum support per project is Rs 22.5 crore
- Capital subsidy for SHP projects in hilly regions/A&N Islands executed by government departments/SNAs - up to Rs 4.5 crore per MW
- Financial support for renovation, modernization and capacity up-rating of old SHP stations - up to Rs 2 crore per MW or 75 per cent of the R&M cost, whichever is lower. The R&M scheme has been extended to cover SHP projects up to 15 MW with a maximum support of Rs 10 crore per project
- Financial support for development/up gradation of water mills: up to Rs 30,000 or 75 per cent of actual cost, in mechanical mode and Rs 60,000 or 75 per cent of actual cost in electrical/electrical plus mechanical mode per mill
- IREDA, the financial institution under MNES, provides Term loans for setting up of SHP projects up to 25 MW capacity in the commercial sector.

1.7 SCOPE OF STUDY

As discussed above the major problem associated with. Micro hydro sites are not standardized. There is no standard procedure available for manufacturing low cost and efficient micro hydro turbines. Generally large manufactures are not interested in manufacturing of small capacity Micro hydro turbine (Capacity less that 100 kW). In the view of above, there is need to find out the cost effective manufacturing techniques for micro hydro turbines in order to make there size plants techno-economically viable. In order to carry out the present study, following has be proposed.

- To study the turbines suitable for low capacity micro hydro sites.
- To study the existing manufacturing methods used by local industry which would be used for turbine manufacturing.
- To suggest the techniques suitable for manufacturing of micro hydro turbines(capacity< 30 kW) keeping in mind points like achieving the shorter delivery time, economical, less maintenance and higher product reliability.
- To suggest design for turbine suitable for micro hydro turbine
- To identify the parts of micro hydro turbine which are sensitive to roughness parameters in order to improve the efficiency and reduced the manufacturing cost.

CHAPTER – 2

EQUIPMENTS FOR MICRO HYDRO POWER PLANTS

2.1 GENERAL

As discussed in previous chapter lot of potential exist in the range of micro hydro and is immediately ready to harness. It has been observed that micro hydro power development has not been techno-economically viable. Based on the practical experiences in the past it has been observed that the concept of large hydro or large capacity small hydro plants has been applied over the entire range of micro hydro, which covers 1 kW to 100 kW. This may be the main reason for uneconomical viability of these plants. Therefore it is proposed to classify the micro hydro range further into 3 categories. The classification has been considered based on the quality of power required by consumers, locally available technology, materials and man power expertise which ultimately affect the various costs of the plants.

- Up to 10 kW
- 11 kW to 30 kW
- 31 kW to 100 kW

The basic components of micro hydro power plants are civil works and electro-mechanical equipments. The concept of selection of electro-mechanical equipment under each category of micro hydro power plant has been discussed below.

2.2 ELECTRO MECHANICAL EQUIPMENT

The electromechanical equipment is considered to be the equipment and the system required to develop the energy available in impound or flowing water to convert it into electrical energy, to control it and to transmit it to a regional power grid.

The major electro mechanical component of power plant are the inlet valves, turbine, draft tube, gates, generator, control and protection equipment and substation for transformation of power to the transmission line voltage. In terms of cost, turbine and generator are considered the main component of micro hydro power plant.

Hydro turbine is a prime mover used for pressure energy available in water at a site into mechanical energy. Various types of turbines being used for SHP station are given in Table 2.1.

Table 2.1: Types of Turbines [9]

Sr No	Type	Turbine	Suitable head	Suitable Specific Speed	Remark
1	Impulse	Pelton	100-500	10-25	Discussed in detail below
		Turgo	40-200	15-60	Discussed in detail below
		Cross Flow	1-200	15-70	Discussed in detail below
2	Reaction	Francis	10-250	70- 340	It is mixed flow; water enters radially and leaves axially. Shaft may be vertical or horizontal
		Propeller	2-25	290-850	Axial flow, blade fixed, vertical or horizontal or slant shaft
		Kaplan	16-40	290-850	Axial flow, blade fixed, vertical or horizontal or slant shaft
		Tabular	2-25	290-850	Axial flow, generator outside, vertical or horizontal or slant shaft
		Bulb	2-25	290-850	Axial flow, generator enclosed, horizontal shaft
		Rim/Straflow	2-25	290-850	Axial flow, generator's rotor mounted on runner blade.

2.3 EQUIPMENT FOR MICRO HYDRO UP TO 10 KW

At most of the site traditional water mills are functioning with poor efficiency. One such traditional Gharat is shown in Fig 2.1.The output of these water mills can be increased considerably by improving the main component i.e. the runner of water mill.

Generally runner is made of wood which is not operating at optimum efficiency. The existing runner is suggested to be replaced by improved runner. Efforts have been made for designing of various types of runner. AHEC has developed a new runner which is simple and 'single piece cast'[10]. Improved water mill runner is shown in Fig 2.2 below.

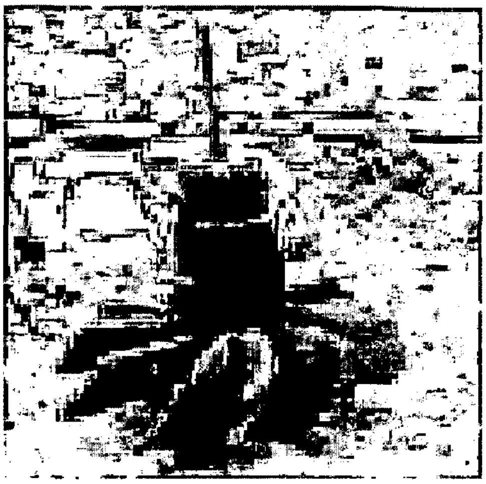


Fig 2.1:Traditional Gharat

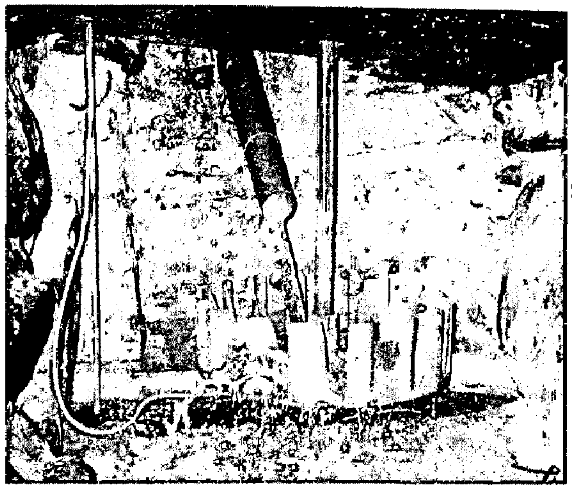


Fig2.2:Improved water mill runner

Bearing is another critical part of water mill. This part requires special attention as most of the loss takes place due to improper bearing resulting in more friction. A better designed bearing developed by AHEC, in which a ball rotates on hardened steel, which is welded on MS plate. It has been reported that these changes improves the efficiency considerably.

A small capacity generator for electricity generation can be fitted with such systems.

2.3.1 For Multi Purpose Power Unit.

At some of the existing water mills sites a sufficient potential are available to develop more power. These sites can be developed by putting simple technology and locally available materials and skills. One multipurpose power unit is shown in Fig 2.3

2.3.2 Turbine

Turbine should be simple, easy to fabricate, easy to operate and maintain. It should be less costly. An open cross flow turbine with horizontal shaft has been considered as a suitable turbine for these sites. Advantage of using open cross flow turbine runner is that it saves the cost in construction as compared to closed one. Whole of the unit can be placed outside the mill building with only shaft and bearing inside.

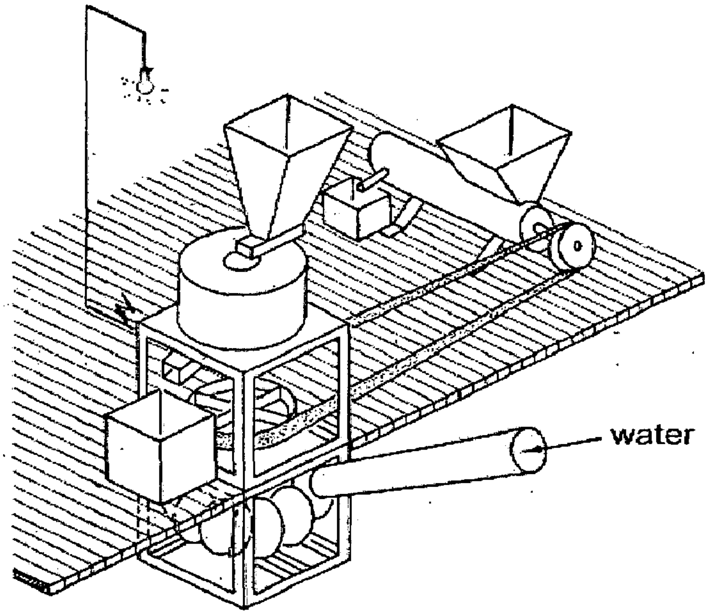


Fig. 2.3 Multi Purpose Power Unit

A thin enclosure of mild steel sheet can be used to avoid the splash of water around the machine. A standard runner which suits almost all such sites has been designed by AHEC. It is made by single piece casting with 24 blades. It can be manufactured in local workshop also if cast facilities are available [11].

Apart from mechanical output it can be coupled with alternator to generate electricity also.

2.2.3 Controller

For mechanical output no governing is needed, but in case of electricity generation, generator performance depends on the load conditions. Governor is an extremely costly item which does not suit Micro Hydro plants of this capacity. Only alternative is to run the turbine back of the power curve. This may not give stable output but eliminates the need for any governing thus saving substantial cost.

2.4 EQUIPMENT FOR 11 kW-30 kW AND 31 kW-100 kW.

As range of 11 to 30 kW and 31 to 100 kW have been recommended for electricity generation, similar equipment for both the categories are suggested for these two categories.

The equipment required are

- Turbine
- Generator

- Controller

2.4.1 Turbine

Types of turbines coming under this range of the micro hydro turbine are,

2.4.1.1 Pelton Turbine

It is called as free jet turbine and operates under the high head of water and, therefore requires less quantity of water. The water is conveyed from reservoir in the mountains to the turbine in the power house through penstocks. The penstock is fitted with a nozzle at the end. Water comes out of jet in the form of free and compact jet. All the pressure energy of water is converted into velocity head. The water having high velocity is made to impinge, in air, on buckets fixed round the circumference of a wheel, the latter being mounted on the shaft. The impact of water on the surface of the bucket produces a force which causes the wheel to rotate, thus, supplying mechanical power on the shaft. One such Pelton turbine is shown in Fig 2.4 .

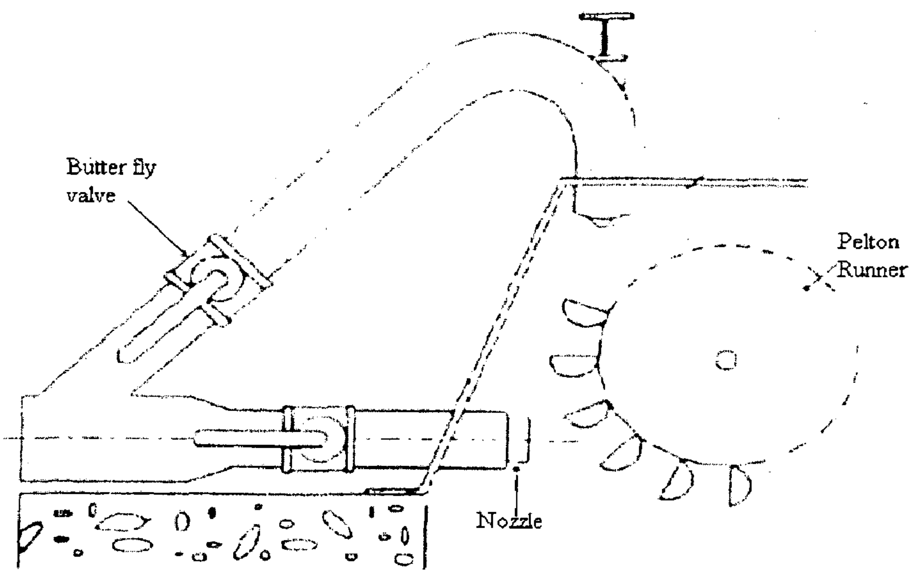


Fig 2.4: Pelton Turbine

Some of the important characteristics of Pelton turbine are

- It has low specific speed (Ns=10-25)

- It is generally used for high head and low discharge runoff river scheme
- There is less chance for the formation of cavitation.
- It has good part load efficiency.
- It has lower peak efficiency than reaction turbine.
- It should be operated above the tail race level as it operates at atmospheric pressure.
- Horizontal Pelton turbine has negligible axial load, thus thrust bearing is not required.
- Comparatively east to repair erosion damage (because the buckets can be replaced easily if cast separately and bolted).
- Although Pelton turbine is generally used for high head, because at low head, the speed become too low and size of runner becomes large. However it can be used for low head also by adopting any of following method
  - Bye using two runners side or on both sides of generators in horizontal settings.
  - By increasing the number of nozzles up to two numbers for horizontal setting and four numbers for vertical setting.

However scope of Pelton turbine is the range of low capacity is limited as mostly sites are of low head range.

2.4.1.2 Cross flow turbine

Cross flow type 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. 2.5.

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.

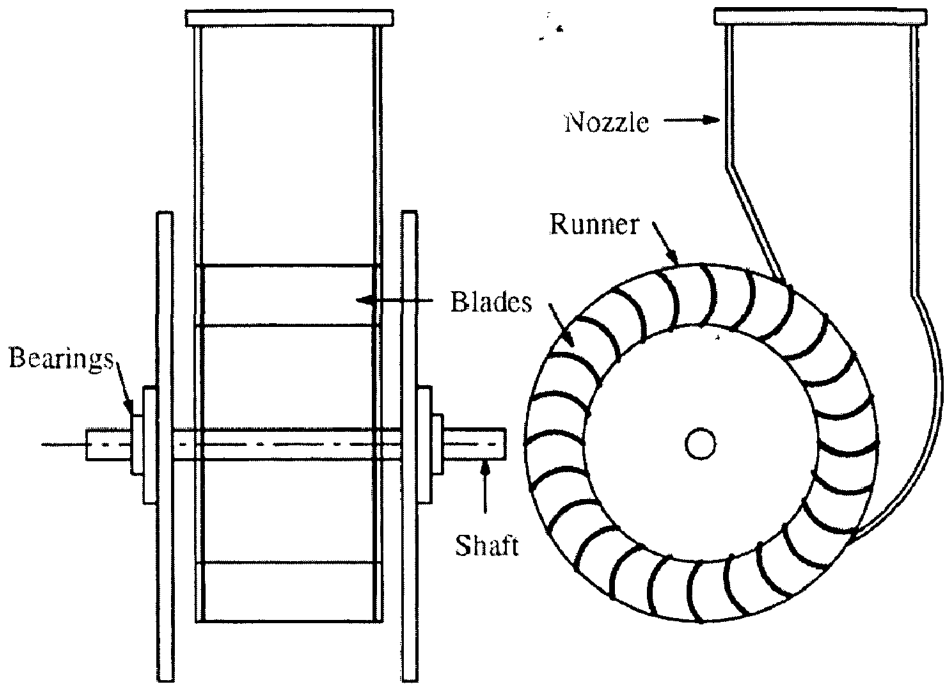


Fig 2.5: Components of cross flow turbine.

Some of the important characteristics of cross flow turbine are

- Because of symmetry of the blades the length of buckets can be increased upto any desired value and hence flow rate.
- Construction simple and easy to fabricate.
- 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.

- It has comparatively low peak efficiency.
- It has specific range from 15-70.
- Operation is convenient and maintenance is relatively easy.

2.4.1.3 Pumps used in turbine mode.

As we know that the problem associated with micro hydro power potential exploitation is primary economic. In general, each proposed site requires individual engineering considerations for the design of an optimized water turbine, the turbine is then costly because of the production of a single machine or a small number of machines tailored to site. One method for reducing the cost of a hydro power installation is to use pumps in reverse mode as turbine. Pump is basically designed as fluid movers for converting mechanical energy into pressure energy. The water enters the suction part at low pressure about shaft work in the impeller and leaves the discharge nozzle at higher pressure. However in reverse mode as turbine, the water at high pressure enters the pump which drives the impeller in reverse mode and leaves at lower pressure. A centrifugal pump is very similar to hydraulic turbine. However one major difference is that pump as turbine is determine by the head under which they operate. There is no efficient way of controlling flow through a pump. On the other hand, hydraulic turbines have efficient way of controlling flow, but that is one reason they cost more. The advantages of pumps as turbines are;

- Because of mass production, they cost less than turbine.
- Because they are standard in size and available off the shelf, delivery times are minimized.
- Easy to handle and maintain due to readily availability of spare parts.

Therefore pump as turbine may be used where no flow regulation is required or a load controller is used and when required power is rather small and initial cost is more important than high efficiency.

2.4.1.4 Turgo impulse turbine

The Turgo turbine is an impulse water turbine designed for medium head application. The turgo has some advantages over Francis and Pelton designs for certain applications. The turgo runner is less expensive to make than Pelton runner and its doesn't need air tight housing like Francis turbine. One such runner is shown in Fig 2.6. It has higher specific speed and can handle more water than the same diameter of Pelton turbine leading to reduced generator and installation cost.

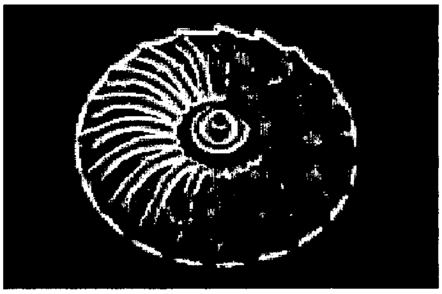


Fig 2.6: Turgo runner

Turgo operate in a head range where the Francis and Pelton overlaps While many large turgo installations exist they are also popular for small hydro where low cost is very important. The turgo turbine is an impulse turbine; water does not change pressure as it moves through the turbine blades. The water's potential energy is converted to kinetic energy with a nozzle. The high speed water jet is then directed on the turbine blades which deflect and reverse the flow. The resulting impulse spins the turbine runner imparting energy to the turbine shaft. Water exits with very little energy.

Like the Pelton, the Turgo is efficient to a wide range of speeds and share the general characteristics of impulse turbine listed for the Pelton, including the fact that it can be mounted either horizontally or vertically. A Turgo runner is difficult to make than a Pelton and the vanes of the runner are more fragile than Pelton buckets. Fig 2.7 shows water impingement on Turgo runner.

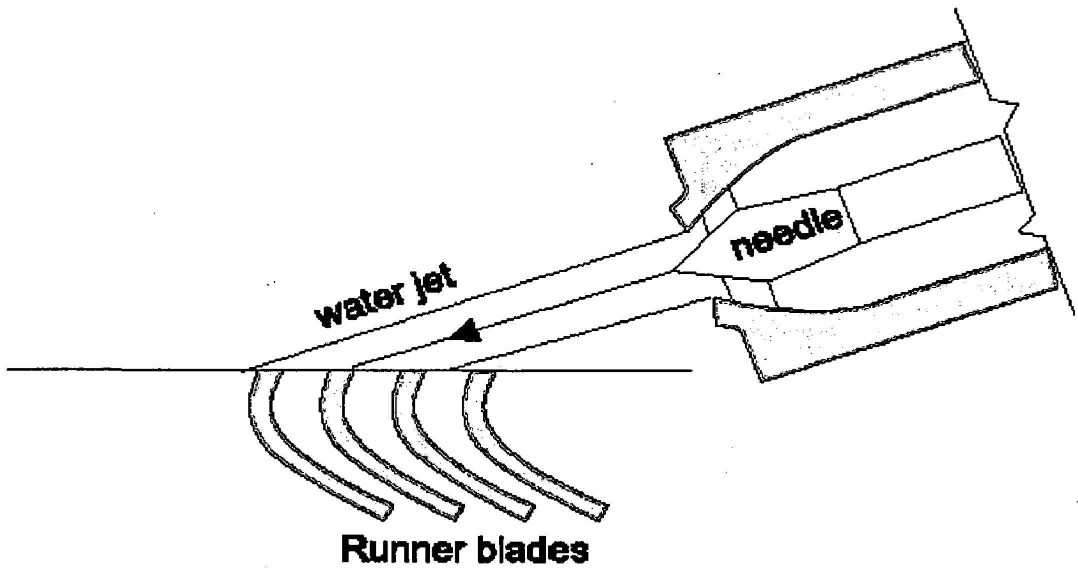


Fig. 2.7 Water Jet Impingement on a Turgo Runner Bucket

A Turgo runner looks like a Pelton runner split in half. For the same power, the Turgo runner is one half the diameters of the Pelton runner, and so twice the specific speed. The Turgo can handle a greater water flow than the Pelton because exiting water doesn't interfere with adjacent buckets

The specific speed of turgo runners is between the Francis and Pelton. Single or multiple nozzles can be used. Increasing the number of jets increases the specific speed of the runner by the square root of the number of jets (four jets yield twice the specific speed of one jet on the same turbine).

2.4.1.5 Francis turbine

Francis turbine can be either being volute-cased or open-flume machine. Fig 2.8 illustrate Francis turbine. The spiral casing is tapered to distribute after uniformly around the entire perimeter of the runner, and the guide vanes feed the water into the runner at the correct angle. The runner blades are profiled in a complex manner and direct the water so that it exits axially from the 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 generally fitted with adjustable guide vanes. These regulate the water flow as it enters the runner, and are usually linked to governing system that matches flow to the turbine loading, along the same line as spear valve or deflector plate in a Pelton turbine. When the flow is reduced, the efficiency of the turbine falls away.

Francis turbine is also limited scope in the low capacity plants in micro hydro range.

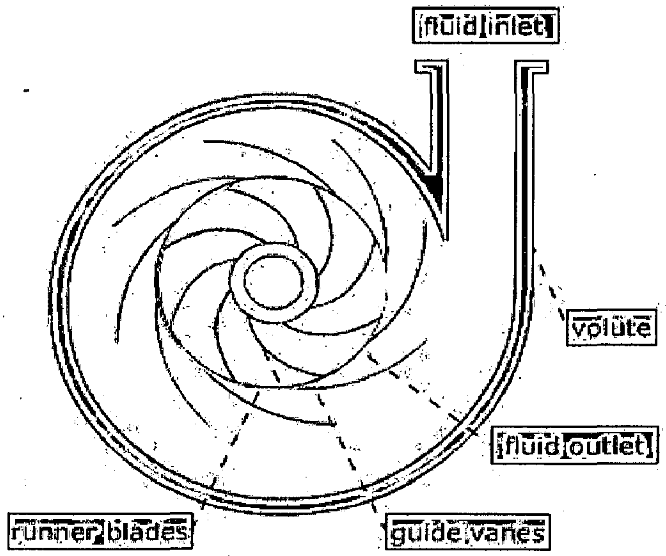


Fig 2.8: Francis turbine

2.4.2 Generator

As par the standard developed by AHEC [12] there are two types of generators namely synchronous and induction. The mounting may be horizontal or vertical depending upon the turbine. The speed is governed by the turbine, except when geared with a speed increaser. For fixed values of power, a decrease in speed will increase the physical size of a generator.

For micro hydro range, all the rotating parts should preferably be designed for full run-away condition. An induction generator has to be designed to withstand run away speed for an indefinite time quite frequently a synchronous has to withstand run away speed continuously for a period of 15 minutes. This requires a very robust mechanical design for both types of generators.

No scope for further designing is there as already various generators of all sizes are available. Induction generators are inexpensive and appropriate for very small schemes below 20 kW. For larger schemes induction generator load controller may not be very reliable. For larger schemes induction generators load controller may not be very reliable. For the required power output, Table 2.2 can be used to select the type of generator.

Table 2.2: Types of generators suitable for micro hydro range.[12]

Description	Up to 10 kW	11 kW to 30 kW	31 kW to 100 kW
Type of generator	First choice: Induction(single or three phase) Second choice: Synchronous	First choice: Synchronous(three phase only) Second choice: Induction(three phase only)	Synchronous (three phase only)

MANUFACTURING PROCESSES FOR LOW COST TURBINE FOR MICRO HYDRO

3.1 GENERAL

In order to make micro hydro site economic viable it is necessary to get equipment at reasonable prize and it is necessary to procure these equipment in standard design. Further the manufacturing procedure should be large and available locally if possible. The manufacturing processes used by various manufacturers are discussed in this chapter.

3.2 PELTON TURBINE

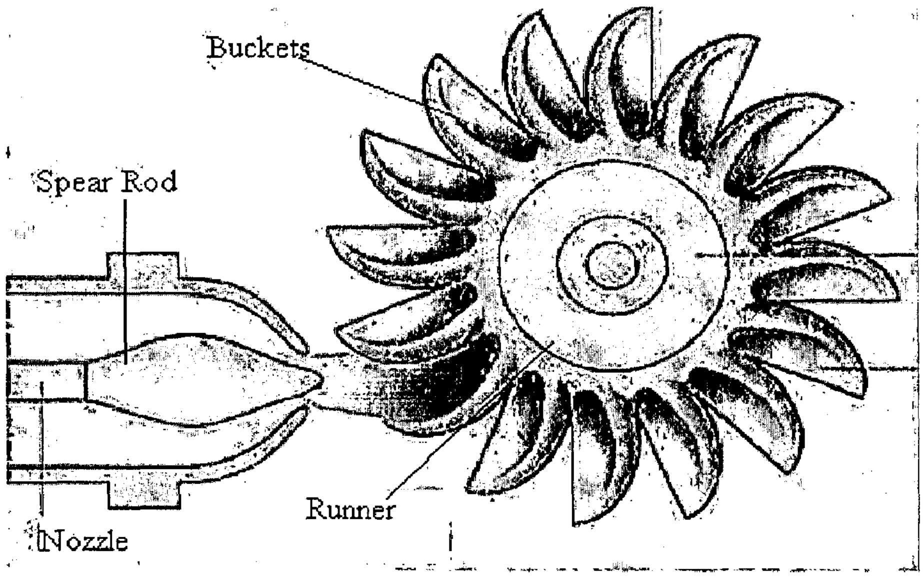


Fig 3.1: Pelton Turbine

Various components of typical Pelton turbine are shown in Fig 3.1. Processes for manufacturing these components are discussed as;

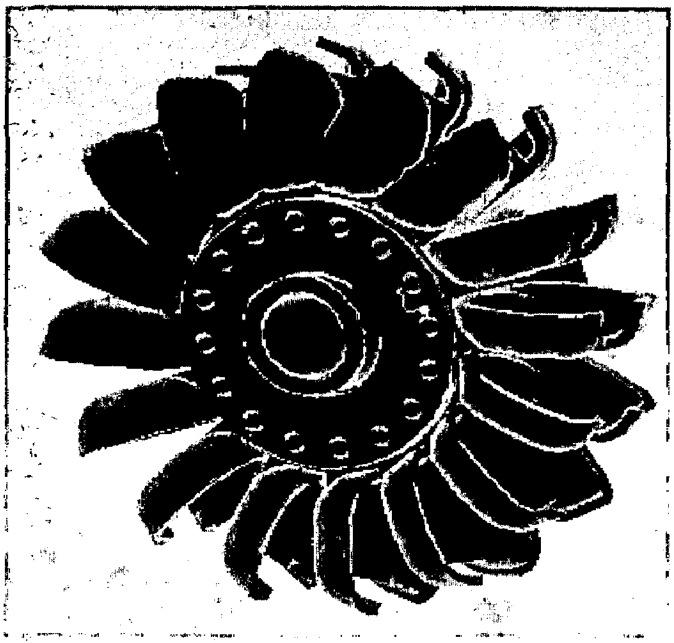
3.2.1 Buckets and Runner:-

There are various techniques of manufacturing of buckets and runner of a Pelton turbine which are discussed as;

3.2.1.1 Mono Block Casting:-

The most commonly used method for manufacturing of large Pelton turbine is mono block casting. In this method runner and bucket are cast in one single piece. Later on they are machined to required accuracy. This is done with the help of advanced milling techniques on multi axis machines.

3.2.1.2 Casting and machining:-



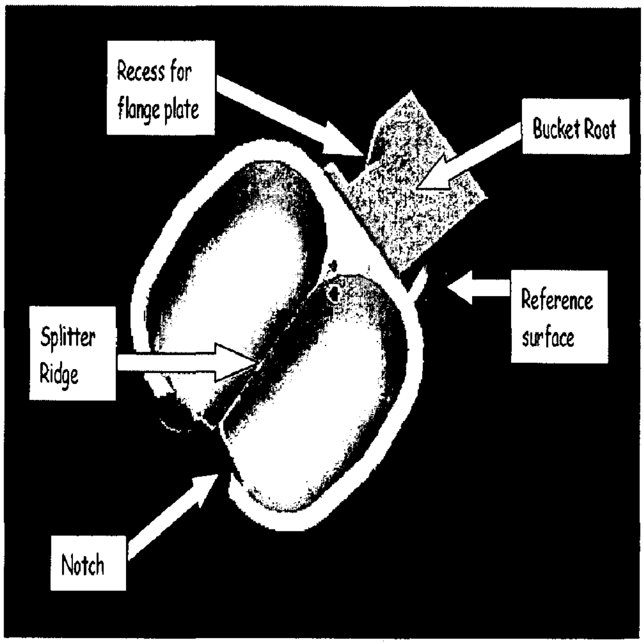


Fig 3.2: A Pelton turbine along with bucket

Individual buckets are cast from suitable casting patterns [13]. Good quality pattern will have an excellent surface finish and sized to allow for the shrinkage that will occur when the shape is cast in metal. For good surface finish and dimensional accuracy casting process used is investment casting. Then the obtained casting is inspected and buckets having large defects or hole is rejected. If the castings have excessive shrinkage on the root then modify casting process is used and the buckets are cast again. The root is important because this is machined to provide reference surfaces and ensure that all the buckets are correctly aligned. Then newly cast buckets are fettled in shot blasting machine to remove excess metal which has resulted from the casting process. The back of the notch is carefully finished with file. Front edge of the notch should be sharp. Due care is taken during the fettling around the notch as shape change around the notch will have significant effect on the bucket performance. Inside surface of bucket is then polished with emery cloth. Surface roughness of the individual bucket can cause a significant reduction in overall performance of runner. Back of the buckets are then machined. The easiest method is to polish the bucket with emery cloth or we can use milling machines or shapers for this operation. The buckets are clamped into the fixture and machined so the there is an equal distance between the side of the root and the splitter ridge on each bucket. This allows the bucket centers to align when they are bolted on the hub. Hole is drilled in each bucket root. Due care is taken about the position of the hole as hole is going to use the clamp the bucket to the hub. End of the bucket is used for reference to mark the position of the bucket. A simple jig is used for this purpose. Then the hole is tap to fit the size of the bolts which are being used to hold the buckets in the place. The final machined bucket is shown in Fig.3.2.

The solid disc is obtained either from plate material or by a forging process. This metal bar is cut to length using available equipment. The maximum possible operations are carried out on one side of the rod before turning around. The face off rod is done and machining is done on other side to bring it to required length and diameter leaving some margin for fillet radius. The drilling is done in the rod just below the tolerance diameter. After this reaming is done to exact the bore required for the push fit, hub is turned around in the lathe and face off. Then this rod is mounted in the dividing head and position of first hole is located with the centre drill and drilling is carrying out to required diameter. Using the dividing head remaining holes are drilled. This drilling in the rod can be done by using the vertical dividing head also.

3.2.1.3 An optimized process

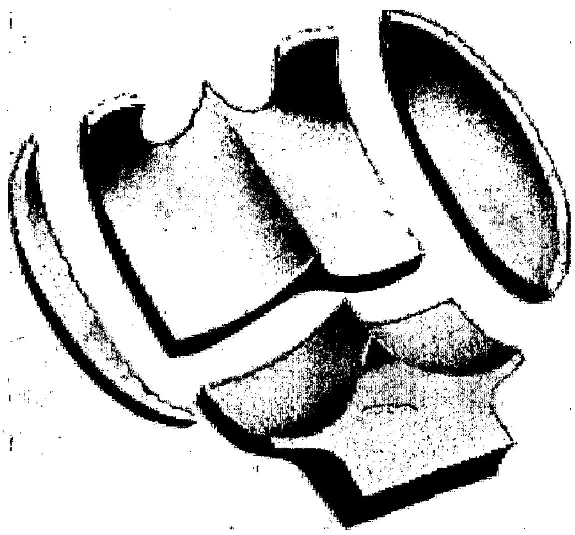


Fig 3.3:Separated bucket

The runner is separated into a centre disk containing the bucket roots. And bucket pieces fixed to root by welding. The choice of bucket separation planes allows fabricating a narrow disk. This ensured the high stresses areas to remain inside the disk; therefore we can use the higher mechanical properties of forged steel [14].

The centre pieces of the buckets are cast with an over thickness. Those pieces are welded on the bucket roots following a sequence to correct continuously the distortion. Inner profiles of the buckets are milled before welding. One such bucket is shown in Fig 3.3. It is also possible to manufacture the bucket pieces by forging process. The runner then is submitted to post weld heat treatment. All the welding areas controlled by non destructive surface and volumetric testing methods before and after the heat treatment. After final machining and cut outs, final polishing is done.

Mastering the welding process is key of this process. The welding test can be performed by using old runner to check the accessibility for welding and non destructive controls and also to define the best suited welding sequence minimizing the distortion. The exact location of the bucket separation is defined through finite element method calculation of stresses, completed in all the bucket volume. The welding is kept out of high stress areas.

With this Pelton runner fabrication process, mechanical properties of materials are increased in all runner areas; in the disk and bucket roots through forged steel, in the middle and lateral parts through high quality of casting or through forged steel pieces, in the welding areas through as adapted qualified procedure reaching higher mechanical properties than integral cast steel and through a 100% controllable welding volume. Manufacturing time is reduced by 30 % in comparison with integral casting runners.

3.2.1.4 MicroGuss

MicroGuss is a fabrication method for Pelton Runners developed by VA TECH HYDRO [15] employing forged material in high stressed zones. One such bucket is shown in Fig. 3.4. The main idea of this method is that root of bucket is machined as integral part of runner disk (that is made of solid forged disk). Afterwards the rest of bucket is established using weld buildup in a robotics welding procedure. At the end the bucket is machined and grinded. Welding of bucket with runner is shown in Fig 3.5. Runner disk is fabricated from forged material, which gives the runner with homogenous characteristics. This disk is pre turned and heat-treated. The complete disk has undergone N-D-T and mechanical testing. Next step is to machining of root of the bucket that is performed on the milling machine.

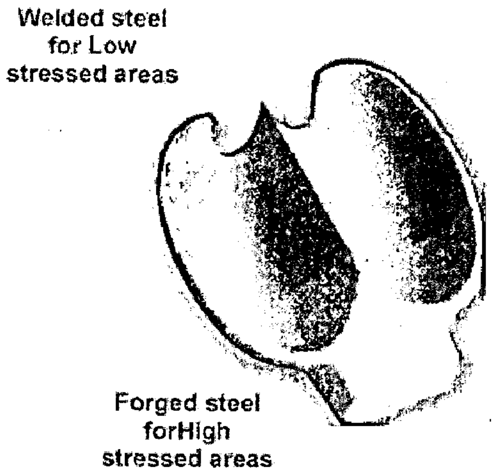


Fig 3.4: Separated bucket

Fig 3.5: Welding of bucket with runner

Outer low stressed section of buckets is build up by automatic welding. Boundary is optimized according to load conditions assuring reliable safety factors. This welded bucket is gone through NC machining that guarantees absolutely precise geometry for optimum efficiency. After that grinding establishes the final profile and assures optimal surface conditions. Then comprehensive quality controls employing NDT, material testing and dimensional control are performed. Protective coating against abrasive wear can be applied to the buckets when high silt concentration or with very hard minerals.

The resistant against corrosion fatigue of this runner is significantly higher than of conventional casting.

3.2.1.5 Method used by Voith Siemens Hydro

In this method cast or forged donut is taken half of geometry of bucket is milled into it along with runner and remaining half is manufactured separately and then welded together by automatic welding procedure using a robot. The position of weld seam must be decided combining the static and dynamic load predicted from a finite element analysis. If the Pelton runner is manufactured from an entire donut 66 % of material will be scraped and the machining cost will have a higher impact. If position of weld is optimized, part of bucket can be manufactured separately on a low cost milling machine with full assurance of material and quality and dimensions and easy inspections. The donut can be easily manufactured by plunged milling techniques, with easy accessibility. The final surface is polished to smooth the weld seam and ensure the adequacy of the intersection of both bucket parts. The discharge angles, inner and outer profiles are inspected using portable digitizing equipment [16].

3.2.1.6 Materials used for runner and buckets

Forged stainless steel Cr Ni 13.4 block, Forged steel, Cast iron, Composite material are the materials use mostly for runner of a Pelton turbine.

Casting of Cr Ni 13.4 steel, Stainless Cast or Forged steel, Aluminum, Stainless steel, Cast iron are the materials used for buckets of a Pelton turbine.

The use of composite materials in turbines allows for a significant mass reduction, decreasing inertia effect (runners) and facilitates the manufacture of complex hydraulic shapes. The cost and time cycle are reduced and fatigue behavior is good. Flexibility is also improved for adapting the strength modulus of the material and structure to local design requirement. Furthermore for this kind of runner the advantage of mass decrease is more evident, as the high head Pelton range implies high tangential speed, and the massive bucket shape penalizes the solid steel design. Vibration of buckets is no longer is problem, compared with steel buckets. A tissue impregnated with carbon-epoxy fibers is taken as composite material. 2 mm thick deposit at Ni-based metal coating.[17].

3.2.2 NOZZLE

The nozzle creates a high pressure water jet which directs the flow at the centre of the Pelton buckets. Correct alignment of the nozzle is critical to achieving the best performance from the turbine. Since the flow is restricted at the nozzle, additional friction losses occur which reduce the net head. The extent of these losses depends on the flow and nozzle design. Losses. Attention should also be paid to the surface finish on the inside. A rough surface will cause a greater frictional loss than a smooth one. The diameter of the hole at the end of the taper is very important as the flow is proportional to the square of the diameter. Following are the processes for fabrication of nozzle.

3.2.2.1 From flat plate and pipe section

Shape the cone around a suitable former using a piece of flat plate and welding along the seam. The former is turned on a lathe.

3.2.2.2 Machined from solid bar

Machine the complete nozzle from a solid bar on the lathe. This will be easier if aluminum bar rather than steel bar is used. A boring bar is required to reach inside the reamed bar and machine to the correct dimensions. When machining the cone, it is necessary to rotate the tool post to the correct angle. Machining of one such nozzle is shown in Fig 3.6.

For small nozzles (jet diameter less than 15mm) it may be necessary to make a narrower boring bar in order to avoid interference when machining the inside tip of the cone.

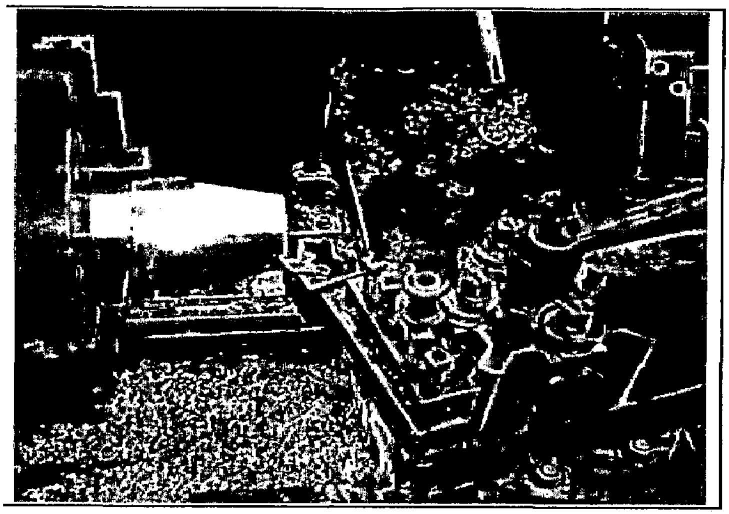


Fig 3.6: Machining of nozzle

3.2.2.3 Use of pipe cap and pipe section

A less efficient, but low cost nozzle can be made by drilling a hole of the correct diameter in a plastic or metal pipe cap. The cap is then threaded onto a section of pipe. The thread should be sealed using suitable means available

3.2.3 METHODS OF FABRICATION FOR NOZZLE PLATE

The plate is cut to size and the holes drilled for the locating bolts. The centre hole is carefully marked. The metal can be removed by drilling and filing out to give a round hole unless another method such as a trepanning tool is available. The nozzle pipe should just fit through Positioning the Generator, runner and nozzle on the base-frame, allows the required length of the nozzle to be judged. The nozzle must be as close to the buckets as possible for maximum efficiency. Slide the nozzle forwards in line with the pitch circle diameter (PCD) of the runner until the buckets almost touch when the runner is rotated. Mark the position where the pipe and the plate meet and weld together. Make sure that the plate is perfectly at right angles to the nozzle to ensure that the jet interacts correctly with the runner. An alternative method of securing the nozzle and plate together is to thread the outside of the nozzle and use back nuts either side of the plate. In this way the distance from the nozzle tip to the runner can be modified during assembly at the site. Use plumbers (PTFE) tape or a similar method to seal between the nuts and thread.

3.2.4 CASING

The casing of Pelton turbine has no hydraulic function to perform. It is necessary only to prevent splashing and to lead the water to the tail race, and also safeguard against accidents. It has to take force of jet projecting beyond the runner in the event of overspread. Methods used for manufacturing of casing are discussed as;

3.2.4.1 Casting:

In this method whole casing is manufactured by casting. This method is useful for small casings. The casting method is used for this is green sand molding.

3.2.4.2 Fabrication:

In this method casing is manufactured by number of sheets fabricated together.

The comparison of various manufacturing processes for various parts along with materials for Pelton turbine is shown in Table3.1 below.

Table 3.1: Comparison of various manufacturing processes used for Pelton turbine

Component	Materials	Manufacturing techniques	Recommendations
Bucket and Runner	Cast Iron	Mono Block Casting	Useful for manufacturing of large Pelton turbine and required advanced milling machines
	Aluminum and Stainless steel	Casting and machining	Suitable for manufacturing of small Pelton turbines. Techniques are readily available. Accuracy depends upon the casting quality and machining accuracy.
	Stainless steel	An optimized process	This is an advance process. Mastering a welding process is key for this process. Manufacturing time is reduced by 30% in comparison with integral casting runners.
	Forged stainless steel Cr Ni 13.4 block	MicroGuss	It employs forged material in high stress zone. Runner is manufactured by forged process. The resistant against corrosion fatigue is significantly higher than of conventional casting. Advanced manufacturing facilities are required fir this process

	Forged stainless steel Cr Ni 13.4 block	Method used by Voith Siemens Hydro	It requires the advance milling machines and welding facilities.
Nozzle	Stainless steel	From flat plate and pipe section	Pressing facility required for this method.
	Aluminum or Stainless steel	Machined from solid bar	This is simple method. Ordinary lathe can be used to manufacture it
		Use a pipe cap and pipe section	Less efficient but low cost nozzle can be made by this method.
Casing	Cast Iron	Casting	Useful for manufacturing for small capacity turbines.
	Cast Iron	Fabrication	Requires press and welding facility. Can be used for both small and large casing.
Runner Shaft	Forged Stainless Steel	Machining	Can be manufactured on simple lathe for less capacity turbines.

3.3 CROSS FLOW TURBINE

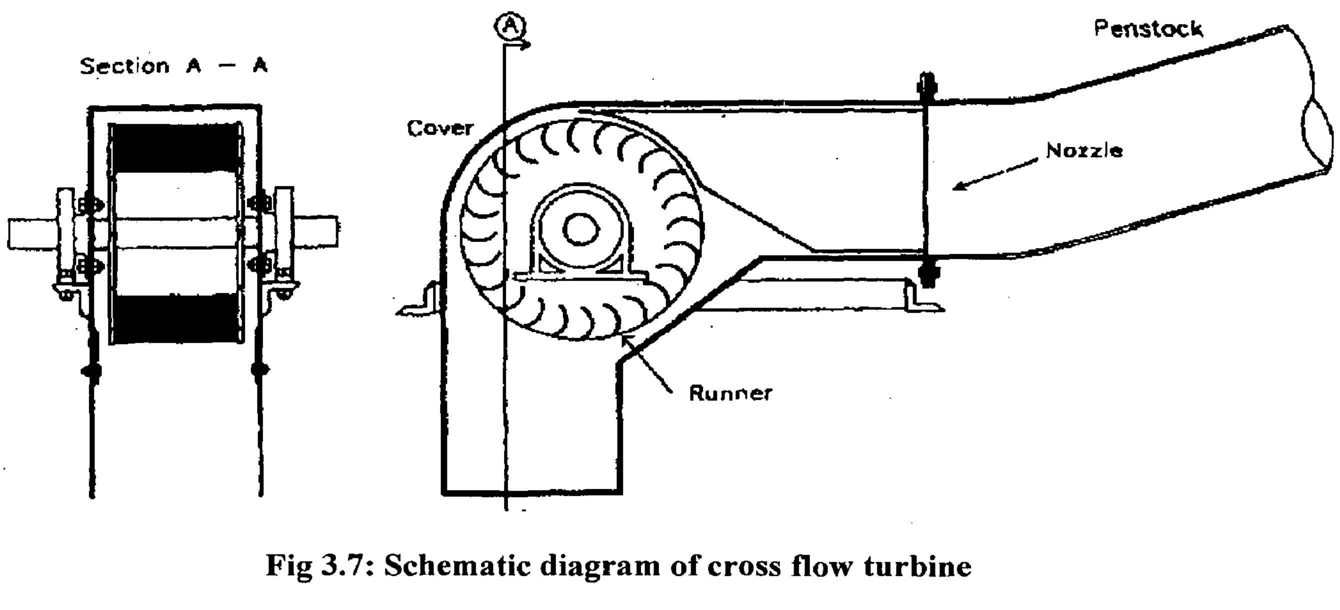


Fig 3.7: Schematic diagram of cross flow turbine

Various components of typical cross flow turbine are shown in Fig 3.7. The fabrication processes of these components are discussed as;

3.3.1 Runner

The cross flow turbine is having cylindrical shape runner. A number of blades fixed between the two disks which rest over the shaft. The water jet does not impart its energy over runner at single stage. When jet enters over the periphery of the runner almost 2/3 of energy is transferred and jet leaving the runner blade at this stage crosses the shaft and hit and transfers the remaining energy in opposite direction over the blade. Methods of runner manufacturing are as;

3.3.1.1 Fabrication method:-

Fig 3.8: Components of Cross flow turbine

The sides of runner are two circular discs which are welded to runner rods and turned for roundness. These side plates are made from the sheet metals. Then runner blades are made individually are made of galvanized steel pipes which split along its length. These blades are carefully arc welded between the side plates. One such cross flow turbine is shown in Fig. 3.8.Then runner is taken to lathe and the blades are carefully trimmed to same roundness as the plates. The runner is then placed on knife edges and weighted to achieve static balance [18].

3.3.1.2 Casting Method -:

In this method whole runner is cast as single piece. For the fabrication of the runner, a wooden pattern is made for a single blade. This single blade is used for making of the Aluminium pattern, so that all the blades of the pattern have the identical dimensions. Aluminium pattern is used for sand mould casting. The runner is cast in cast steel. The runner after casting is then machined to dimension and the blades are given smooth finishing with the help of grinder. The key ways are then cut inside the hub to mount it on the main shaft.

Various steps for fabrication are given below;

(i) Master pattern is made with the help of detailed drawing showing blade profile by considering all allowances.

(ii) Now using master pattern, an Aluminium pattern is made. This is to ensure that, blades of cross flow turbine come out correctly in every casting. Main advantage of Metal pattern is that, it can be used for long runs, there is no damage to pattern in comparison to wooden pattern.

(iii) Cross flow turbine is cast in foundry in following steps;

- First of all cupola and rotary furnace is charged for melting pig iron. Pig iron is melted in cupola and melt is carried to rotary furnance and it is heated to pouring temperature and composition of melts are maintained by adding other scrapes, in it.
- When melting is going on, hand moulding is carried out near the furnace. This is done by placing the placing the pattern in mold box. Then sand is sprinkle on the pattern. This sand is set down by ramming. Then pattern is removed from the rammed sand and mold cavity is formed. Then core is placed inside the cavity in right position. Then metal is poured in this cavity and is allowed to cool down. Then mold is break down and shot blasted for cleaning.

(iv) Cast runner is then turned and bored on a lathe, then it is statically balanced. Grinding and drilling is done to remove any imbalanced weight

3.3.2 NOZZLE

Taper nozzle is fabricated out of sheet metal 4" dia on one end and 5", 6" or 8" dia of other end (penstock end) as per the drawings. It is fixed in position by grouting in adjusting wall or clamping on base frame providing 1 mm clearance over the runner at the time of installation. Generally anchor block is providing to support the nozzle along with the control valve and the penstock. The fabricated nozzle along with the valve is shown in Fig.3.9

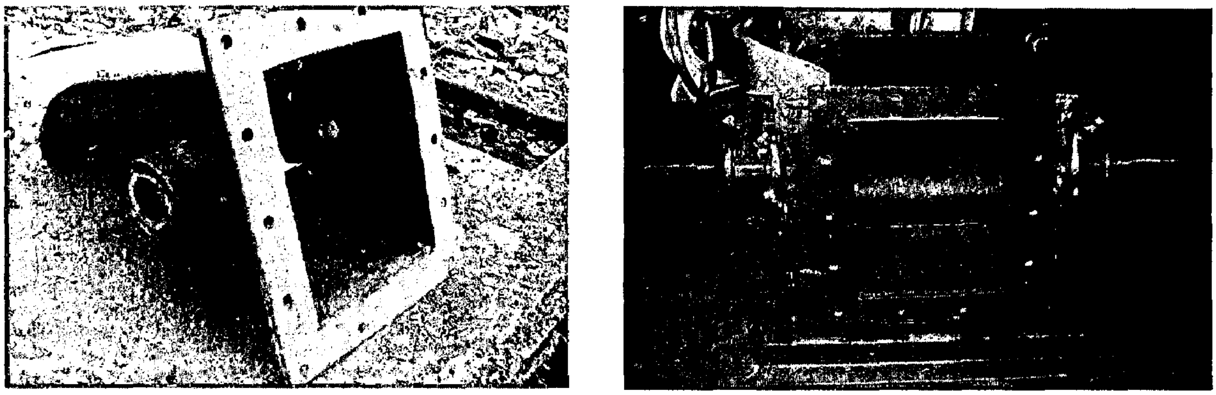


Fig 3.9: Nozzle and Valve for cross flow turbine

The comparison of various manufacturing processes for various parts along with materials for cross flow turbine is shown in Table3.2 as;

Table 3.2: Comparison of various manufacturing processes for cross flow turbine

Component	Materials	Manufacturing techniques	Recommendations
Runner	Stainless Steel	Fabrication	It is simple method of manufacturing of cross flow turbine. Turbine can be manufactured within limited manufacturing facilities.
	Stainless Steel	Casting	Whole runner is cast into single piece. Accurate pattern and machining of cast profile is key of this process.
Splash cover	Cast Iron	Casting	Useful for manufacturing for small capacity turbines.
	Cast Iron	Fabrication	Requires press and welding facility. Can be used for both small and large casing.
Runner Shaft	Forged Stainless Steel	Machining	Can be manufactured on simple lathe for less capacity turbines.

Out of Pelton, Cross flow, Turgo impulse, pump as turbine and Francis turbine, this study is restricted to Pelton and cross flow turbines. As Francis turbine is having big size for low capacity and its runner is critical to manufacture. As Francis runner is single piece casting so it requires full fledge casting and machining facilities.

For pump as turbine we can use it but its selection is problem and for same capacity of turbine, pump is having less efficiency.

For Pelton, Turgo impulse and cross flow turbine manufacturing it has been found, following procedures are currently used by large manufacturers

- Mono block casting
- Casting and fabrication
- An optimized process
- Microguss
- Method used by Voith Siemens Hydro

Out of this for micro hydro turbines (capacity less than 30 kW) that is Pico turbines; we can apply casting and fabrication procedure for efficient manufacturing of turbines. As rest of processes requires advanced manufacturing facilities and hence cost will be more. In casting and fabrication process we can cast buckets in foundry and machine them on simple lathe and milling machines. For smooth flow of water over the bucket we can make use of coating over the bucket. Similarly we can machine runner, hub, nozzle, and casing.

There is another option for manufacturing of bucket is use of forging procedure.

3.4 MATERIAL INVESTIGATION

The material selection process is the key to engineering any application and/or part design. This selection process can be defined by application requirements, possible materials, physical principles, and selection. The design or function of the part/application is the application requirements. The application requirements are specific given the application. The possible materials are simply the only materials that can be used in the application. Possible Materials are defined by the application requirements.

Physical principles are methods of changing a material that are learned through material science techniques. Using material science physical principles we can change material properties. Three common physical principles we can use for functional material trengthening are densification, composites, and alloying. There many manufacturing techniques used to strengthen and form materials as well.

Densification is the most common and necessary way to strengthen any material. In general, this increases the tensile strength by reducing the porosity of the material. The standard composite rule of mixtures is when the standard matrix is soft/pliable and the reinforcing material is tensile strong. One the major reasons for the prevalent use of composite materials in construction is the adaptability of the composite to many kinds of applications. The selection of mixture proportions can be aimed to achieve optimum mechanical behavior of the harden product. Selection can result in the change of the strength, consistency, density, appearance, and durability.

The alloying of metals is one of the oldest and most fundamental material processing techniques. An Alloy is a solid solution that is composed of two or more elements. There is a solvent (majority composition) and a solute. The Solute element can strengthen the overall solid solution by different element size, density, and other material properties.

Given the application requirements, possible materials, and physical principles it can be possible to select the best material. Thus in the selection of a material: First, decide on the requirements of the application. Second, decide on the possible materials that can be used in the application. Third, decide what changes in the material properties are needed. Lastly, decide which material out of the possible materials best fulfills the requirements of the application given possible changes in the material properties.

3.4.1 Application requirement

As always the major overall turbine requirements are speed, safety and reliability. The turbine weight is the key to speed, but the lightweight need must be balanced by the other factors (safety and endurance). The Table 3.3 gives a brief outline of the application requirements.

3.4.2 POSSIBLE MATERIALS

The following is a description of materials commonly used for turbine construction

3.4.2.1 Carbon Steel Pipe

This material is used in all turbine components of plate steel construction. This is low to intermediate strength materials and has a cavitation resistance which is typical of carbon steel.

3.4.2.2 Carbon Steel Castings

:se materials are commonly used for turbine runners. These materials are used creased mechanical strength is required.

3: Application requirement

tion	Function	Wear	Strength	Cost	Weigl
Runner	Moving mechanical part	High mechanical wear	Need varies	45%	35%
te and :nsion	Core structure	Stress/strain loading	Tension/compression strength	10%	20%
Shaft	Core structure	Stress/strain loading	Tension/compression strength	5%	10%
	Assembling		Tension strength	3%	5%
	Guide	Mechanical wear	Need varies	20%	15%
	Support			5%	5%
	Avoid splashing of water	Corrosion	Corrosion resistant	5%	10%

.3 Stainless Steel Plate

This material is used on all turbine components of stainless steel plate :ion. The material is easily weldable and strength equivalent to low strength eel.

.4 Stainless Steel Castings (Martensitic)

These castings are commonly used for turbine runners. These materials :er weld ability and better casting behavior. Filed repairs with austenitic weld are feasible with minimal preheat and no post weld heat treatment. This is of relatively high strength, and has a cavitation resistance comparable to plate. Because of relatively low chromium and nickel content, the material is ɔ pitting in salt water or similar corrosive environment. In some installation of the material is believed to be result of contamination of the material surface e manufacturing process. For salt water application, a higher chromium content ic stainless steel has been developed.

3.4.2.5 Stainless Steel Castings(Austenitic)

This material is an 18-8 austenitic stainless steel and is also used for runners. Castings from this material are easily field welded and more corrosion resistant than stainless steel. However, the austenitic material is lower in strength than martensitic stainless steel and more costly because of the higher nickel content and increased casting difficulties.

3.4.2.6 Stainless Steel Overlay

Stainless steel welded overlay using austenitic stainless weld material is common on cavitation-prone areas of carbon steel turbine components. The overlay is usually 1/8 inch (3mm) or 3/16 inch (5mm) minimum thickness and has cavitation resistance equal to or better than stainless steel castings and plate. This material is used in deeply pitted areas as a first pass over the carbon steel to reduce the possibility of weld cracking.

3.4.2.7 Aluminum Bronze Castings.

This material may be used as an alternative to cast stainless steel and has comparable cavitation resistance. However aluminum bronze is lower strength and large casting are higher in cost. Also out of position welding is difficult, causing problems for in-place repair work. Aluminum bronze is restricted to smaller runners. For salt water application bronze offers increased corrosion resistance over stainless steel.

3.4.2.8 Composite Materials

The use of composite materials in turbines allows for a significant mass reduction, decreasing inertia effect (runners) and facilitates the manufacture of complex hydraulic shapes. The cost and time cycle are reduced and fatigue behavior is good. Flexibility is also improved for adapting the strength modulus of the material and structure to local design requirement. Furthermore for this kind of runner the advantage of mass decrease is more evident, as the high head Pelton range implies high tangential speed, and the massive bucket shape penalizes the solid steel design. Vibration of buckets is no longer is problem, compared with steel buckets. A tissue impregnated with carbon-epoxy fibers is taken as composite material. 2 mm thick deposit at Ni-based metal coating. The Table 3.4 shows the properties of materials that can be used for manufacturing of turbines.

Table 3.4: Properties of materials

	Modulus of Elasticity (GPa)	Ultimate tensile strength	Yield Stress	Elongation at failure	Density (*1000 kg/m^3)
Steel	190-210	340-1900	280-1600	3-40	
Cast iron	83-170	69-480	120-290	0-1	7-7.4
Aluminum	70	70	20	60	2.71
Aluminum Alloys	70-79	100-550	35-500	1-45	2.64-2.8
Bronze	96-120	200-830	82-690	5-60	7.8-8.8

3.4.3 Material selection

Given with presented applications, possible materials, and physical principles we can gather our resulting material selection considering with cost and without cost, this is shown in Table 3.5. The factor of cost for the materials is difficult to examine because vast additional manufacturing, design, and material processing cost/factors.

Table 3.5: Final material selection

Application	**Material without cost**	**Material with cost**
Buckets	Aluminum/Bronze/Steel	Aluminum/Bronze
Hub Plate and Hub extension	Steels	Steels
Runner Shaft	Steels	Steels
Nozzle	Steel/Aluminum	Aluminum
Casing	Cast iron/Steel	Cast iron/Steel

DESIGN AND COSTING OF LOCALLY MANUFACTURED MICRO HYDRO TURBINE.

4.1 GENERAL

As mentioned earlier that, micro hydro scheme are those with unit ratings of less than 100 kW and these plants (MHP) are often situated in remote communities, particularly in developing countries and they are often isolated from grid networks. Their characteristics are such that, they require special regulating or management approaches. Moreover, the communities, which install these sets usually, have limited finance and limited skilled labour, if any, to operate and maintain the equipment. Unfortunately, as the power rating of hydroelectric plant decreases then the cost per unit increases. For community to afford a micro hydroelectric generating unit the capital cost of the plant must be as low as possible and the plant must be simple to install, operate and maintain. A typical example for trend in per kW installation cost with capacities of the plants is shown in Fig 4.1.

In order to exploit the large potential available in this range, the capital cost must reduce. The approach to develop a micro hydro plant must be different from that applied to larger hydro plant. By examining the civil, hydraulic and electromechanical factors, which contribute to the rise in unit costs as the power plant capacity decreases, it may be possible to identify the scope to reduce the cost.

Based on field experience it is found that the cost of turbine for these plants can be reduced subsequently by compromising with efficiency. Under this chapter a case study is taken to examine the extent of reduction in cost of fabrication has been taken. Two types of turbine Pelton turbine and cross flow turbine have been considered. Design of these turbines of typical sizes are given for fabrication.

4.2: PARAMETER CONSIDERED FOR PELTON TURBINE

Data for a typical site [20]

Discharge Q= 0.036 m^3/s and

Head H= 68.00 m.

End use = household electrification

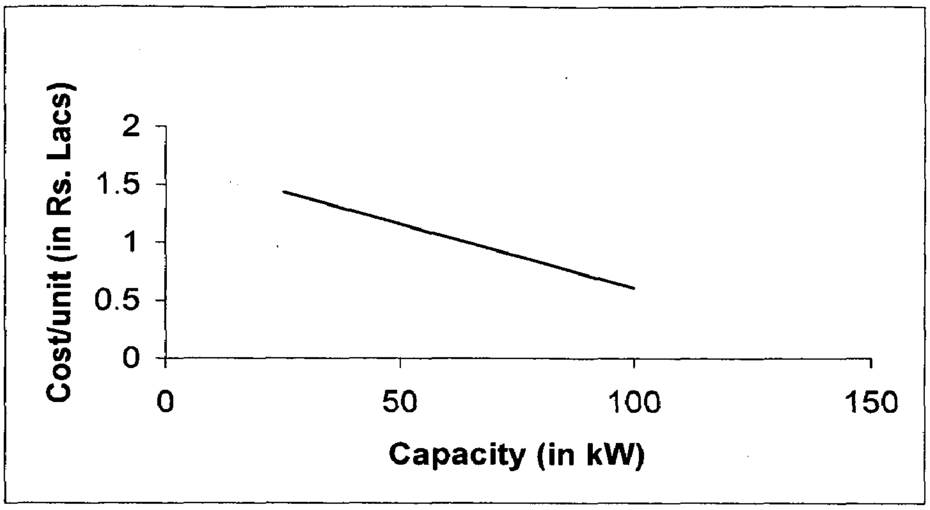


Fig 4.1 Variation in Cost/Unit with Respect to Plant Capacity [19]

Specific speed for the given site is calculated as follows

Specific Speed (Ns) $= \dfrac{N\sqrt{P}}{H^{5/4}}$

$= \dfrac{1000\sqrt{20}}{68^{5/4}}$

$= 23$

Therefore Pelton turbine is selected for given site conditions. The dimensions of Pelton turbine are calculated as;

4.2.1 Velocity of jet (v)

$V = k_v (\sqrt{2*g*h})$

$= 0.98*(\sqrt{2*9.81*68})$

$= 34.79\ m^2/s$

4.2.2 Diameter of nozzle(d)

$Q = \dfrac{3.142}{4 \times d^2 v_{jet}}$

$$0.036 = \frac{3.142}{4 \times d^2 \times 35.79}$$

d= 36.00 mm

It is assumed throughout that jet and nozzle diameter are equal. In practice the jet diameter is marginally smaller but this difference can consider negligible for micro systems.

4.2.3 Runner diameter (D)

$$\frac{u}{v} = 0.46$$

$$u = 0.46 \times V_{jet}$$

$$\frac{3.142 \times D \times 1000}{60} = 0.46 \times 34.79$$

D= 314.42 mm

4.2.4 Number of buckets(Z)

$$Z = 0.4 \frac{D}{d} + 14$$

Z= 20

4.2.5 Design of buckets

Length= 2.3*d= 2.3*36= 83 mm

Width= 2.8*d= 2.8*36= 101 mm

Depth= 0.6*d= 0.6*36= 22 mm

Inlet angle $\beta_1 = 6^0$; Outlet angle $\beta_2 = 14^0$ at centre.

Size of root of bucket= 40*24 mm

The dimensions of bucket are shown in Fig 4.3.

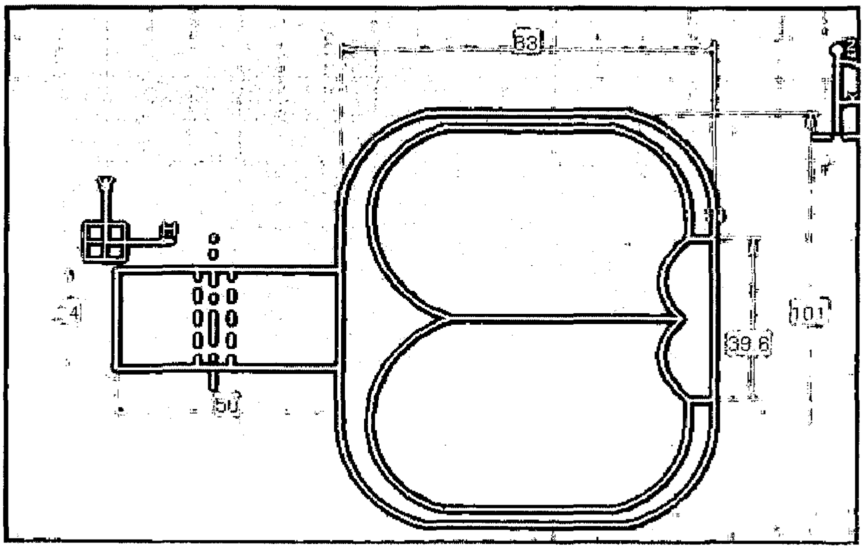


Fig 4.2: Bucket

4.2.6 Design of bolts

$$P=\frac{2\times 3.142\times N\times T}{60}$$

$$20*10^3=\frac{2\times 3.142\times 1000\times T}{60}$$

T= 1909840.90 N-mm

$$T=\frac{3.142}{4}\times d^2\times f_s\times n\times\frac{D_1}{2}$$

$$190984=\frac{3.142}{4}\times d^2\times 70\times 20\times\frac{314}{2}$$

d= 1.10 mm (Safe size) we choose M8.

4.2.7 Hub diameter

D= 314-(24+41.4)*2

= 181 mm.

4.3 COST EFFECTIVE TECHNIQUES FOR VARIOUS COMPONENTS

The main aim of the manufacturing micro hydro turbines is to reduce the cost as well as increase in the efficiency. The manufacturing process used for various components are discussed below. This is given by keeping in the mind that most of the micro turbines are going to be manufactured locally.

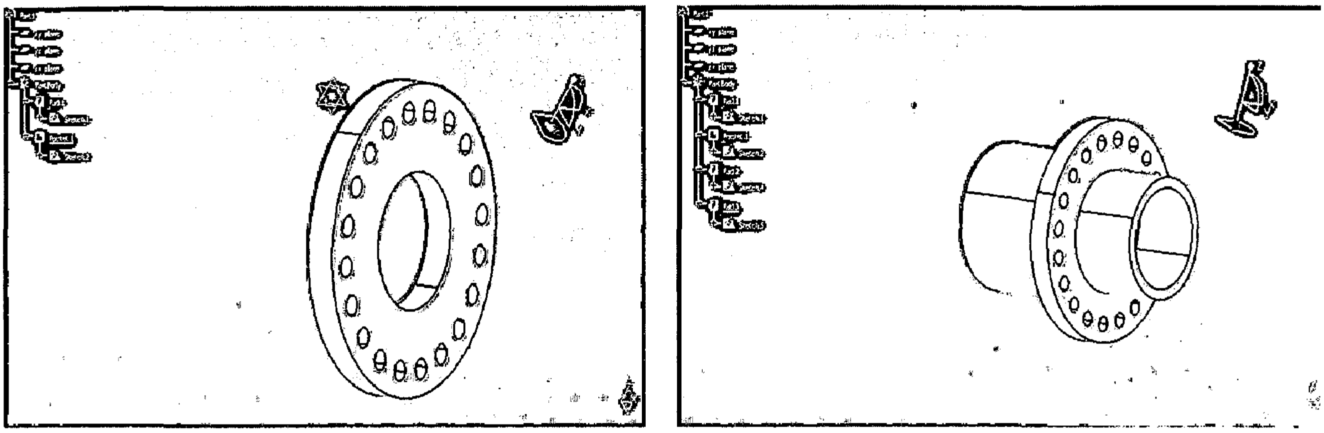


Fig 4.3: Hub and Hub extension for turbine

4.3.1 Bucket

Buckets are cast into separate single pieces. This has an advantage that buckets can be manufactured in batch production. And machining of buckets is easy because it's easy to access various parts of buckets as compare to mono block casting. This also facilitates manufacture that he could outsource buckets from other manufacturers. The process used for casting of buckets is green sand molding. Materials used for manufacturing of buckets are aluminum/ bronze which can be easily cast by green sand molding. And casting of this material is low in cost as compare to steel casting due to points such as low melting point, easy cast ability etc.

4.3.2 Hub plate and hub extension

These parts can make from steel rod by machining on simple lathe. And holes can be drilled by vertical drilling machine. The materials can be used for this, are stainless steel, mild steel.

4.3.3 Nozzle

Nozzle can be machined from rod, on lathe machine. The materials can be used for this are stainless steel or aluminum. Generally stainless steel is preferred because of its easy of machining and it resistance to wear in sand contained water.

4.3.4 Casing

Casing has not performed any mechanical function. It has only to protect turbine and avoid of splashing of water. So it can be made from steel sheets by folding at required points. This cane

4.4 COSTING OF MICRO HYDRO TURBINE

After designing various parts of Pelton turbine the next step in to work out its manufacturing cost. This cost is worked out by consulting with local manufacturer by keeping in mind the available facilities, availability of material for various components and manufacturing processes. The cost of 20 kW Pelton turbine is worked out and is shown in Table 4.1.

Table 4.1: Costing table for Micro hydro turbine (Pelton turbine)

Part name	**Material**	**Manufacturing Process**	**Approximate cost required to manufacture(Rs)**
Bucket	Bronze	Casting	10000/-
Hub plate	Stainless Steel	Machining from solid bar	1400/-
Hub Extension	Stainless Steel	Machining from solid bar	1400/-
Runner shaft	Stainless Steel	Machining	1400/-
Bolts	Stainless Steel	Ready made	140/-
Nozzle	Stainless Steel	Machining from solid bar	3000/-
Bearing			340/-
Casing	Stainless Steel sheets	Press work	400/-
Auxiliaries			400/-
		Total	**18900/-**

The percentage wise distribution of cost of various parts of Pelton turbine is shown in Fig 4.4. From above analysis it is clear that, critical components of micro hydro turbines from manufacturing point of view are runner, nozzle. They are contributing most of the turbine cost also. So if we can achieve some saving or process optimization then it would be direct contributing to the cost as well as efficiency.

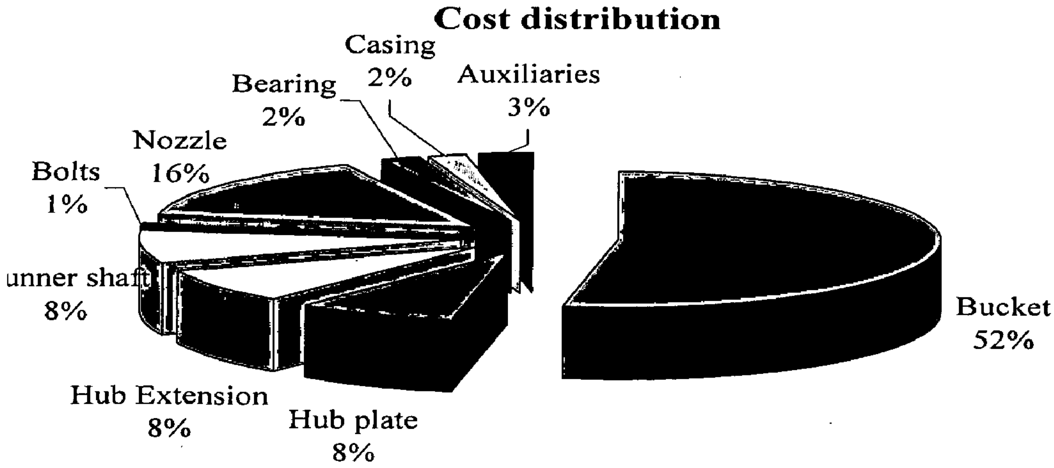


Fig 4.4: Graph of manufacturing cost distribution for Pelton turbine.

4.5 PARAMETERS CONSIDERED FOR CROSS FLOW TURBINE

Data for a typical site [21]

Discharge Q= 0.093 m^3/s and

Head H= 36.00 m.

End use = household electrification

Specific speed for the given site is calculated as follows

$$\text{Specific Speed (Ns)} = \frac{N\sqrt{P}}{H^{5/4}}$$

$$= \frac{1000\sqrt{25}}{36^{5/4}}$$

$$= 46$$

Therefore Cross flow turbine is selected for given site conditions. The dimensions of Cross flow turbine are calculated as;

4.5.1 Circumferential velocity (u)

$$u = k_u \times \sqrt{2 \times g \times h}$$

$$= 0.44 \times \sqrt{2 \times 9.81 \times 36}$$

$$= 11.94 \text{ m/s}^2$$

4.5.2 Runner Diameter(D)

$$u = \frac{\pi \times D \times N}{60}$$

$$D = \frac{60 \times 11.95}{\pi \times 1000}$$

$$D = 0.22 \text{ m}$$

The cross flow blade geometry along with runner shown in Fig. 4.5

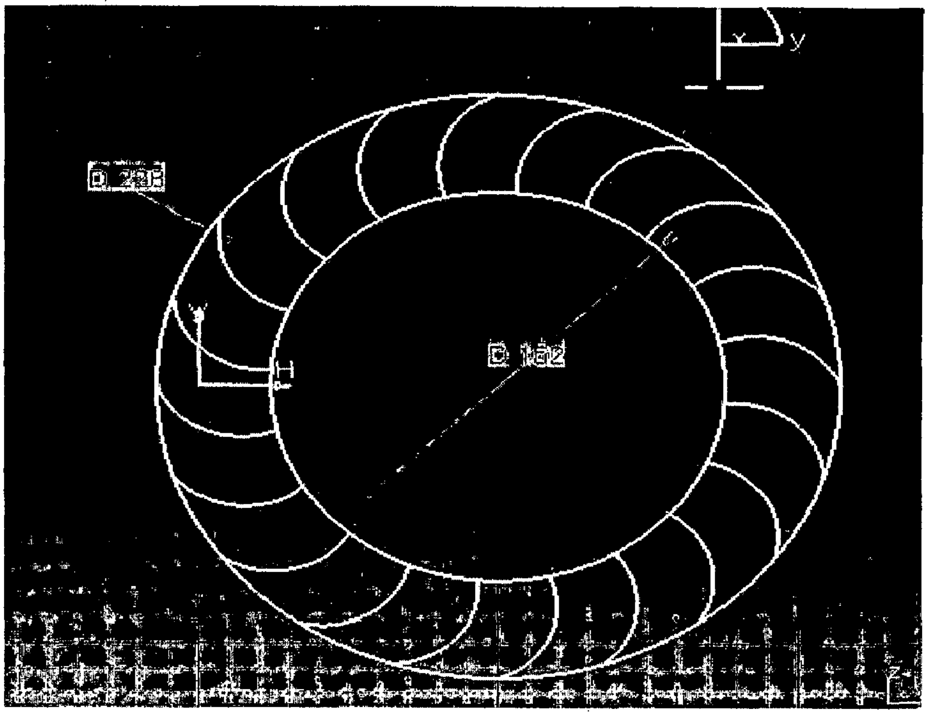


Fig 4.5: Cross flow runner along with blade profile

4.5.3 Runner length(L)

$$L = \frac{Q}{D \times k\sqrt{2 \times g \times h} \times \sin\alpha}$$

$$L = \frac{0.93}{0.22 \times 0.9\sqrt{2 \times 9.81 \times 36} \times \sin 16^0}$$

$$L = .047 \text{ m}$$

4.5.4 Width of nozzle(b_o)

$$b_0 = \frac{k_b \times Q}{D\sqrt{h} \times \sin\alpha}$$

where

$$k_b = \frac{360}{\pi \times 90 \times \sqrt{2 \times g}}$$

$k_b = 0.28$

$$b_0 = \frac{0.28 \times 0.093}{0.228 \times \sqrt{36} \times \sin 16}$$

$b_0 = 0.07$ m

The cross flow nozzle is shown in Fig 4.7

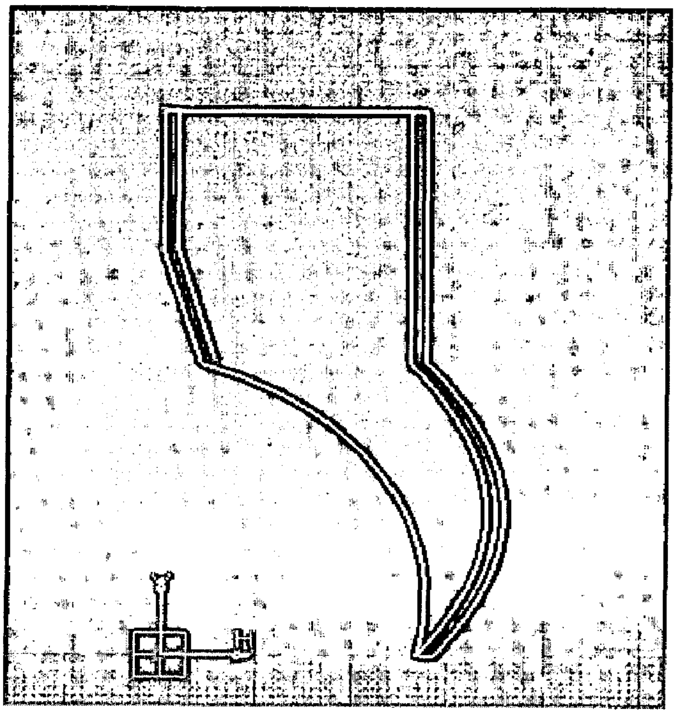


Fig 4.6 Nozzle for Cross flow turbine

4.5.5 Number of blades = 20

4.5.6 Inner radius of runner (R_2)

$$R_2 = 0.666 \times \frac{0.228}{2}$$

$R_2 = 0.076$ m

4.6 COSTING OF MICRO HYDRO TURBINE

After designing various parts of Cross flow turbine the next step in to workout its manufacturing cost. This cost is worked out by consulting with local manufacturer by keeping in mind the available facilities, availability of material for various components and manufacturing processes. The cost of 25 kW Cross flow turbine is worked out and is shown in Table 4.2.

Table 4.2: Costing table for Micro hydro turbine (Cross flow turbine)

Part name	**Material**	**Manufacturing Process**	**Approximate cost required to manufacture(Rs)**
Blade	Stainless Steel	Casting	5000/-
Side Plates	Stainless Steel	Machining from solid bar	1400/-
Runner shaft	Stainless Stell	Machining	1400/-
Nozzle	Stainless Steel	Machining from solid bar	4000/-
Bearing			340/-
Casing	Stainless Steel sheets	Press work	400/-
Auxiliaries			400/-
		Total	**12950/-**

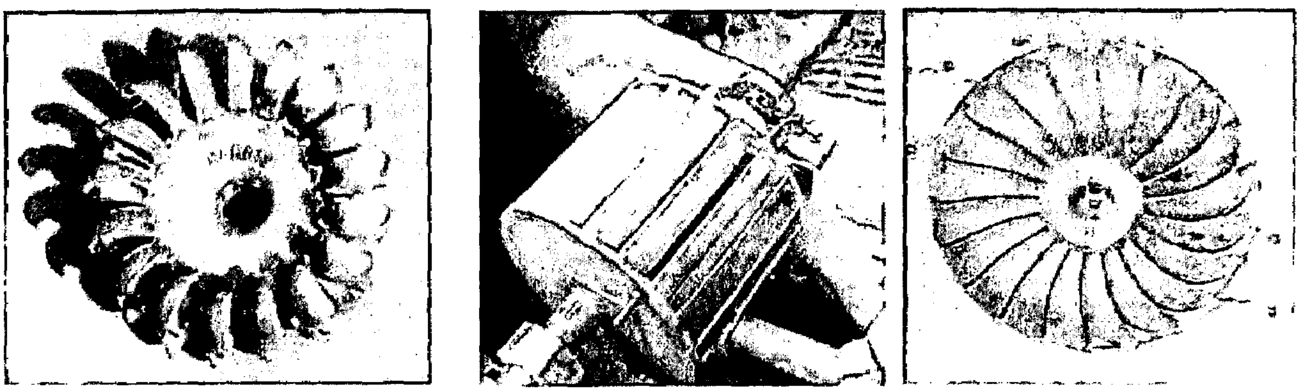
4.7 RUNNER

Runners are manufactured as one-piece castings, cast component welded together, fabricated component welded together, or a combination of cast and fabricated components welded together. In addition, areas of the runner may be weld overlaid with cavitation resistant material. The basic design of the runner will be a function of the state of art of material science, the cost of materials, fabrication and foundry costs, and anticipated duty of the machine. The different types of runner are shown in Fig 4.7

4.7.1 Processes used for manufacturing of runner:

The process that can be used for manufacturing of runners of Pelton, Cross flow and turgo impulse is casting and machining.

The casting processes that can be used for manufacturing of runner are



Pelton buckets and runner Cross flow runner Turgo impulse runner

Fig 4.7: Various types of runner used in manufacturing of micro hydro turbines

4.7.1.1 Green sand molding

The term Green Sand denotes the presence of moisture in molding sand and indicates that the mold is not baked or dried. Raw sand is mined and then processed to give it a consistent distribution of grain sizing. When processed for molding, organic clays are added to bond the grains together. A coal dust (known as Sea Coal) is added to control casting quality during expansion of the sand when hot metals are poured into the molds. Other additives, such as pitch, cellulose and silica flour, are also used. The additive used depends on the metal cast. The sand is blended in a mullor or mixer, where the water and the additives are blended with the sand.

The sand is then ready to be used to make a mold. There are several methods of molding but all methods squeeze or compact the sand against a pattern to make an impression of the part to be cast. The patterns are separated from the mold halves or mold cake and the mold is then closed creating a part cavity. Types of molding range from automatic high-pressure high-speed molding, automatic match plate molding, automatic tight flask molding (used for large molds) and jolt squeeze molding. Large molds are also made on the floor and rammed up by hand. Today, molding is primarily done automatically and the molds are placed on mold handling equipment to be poured, to allow the castings to solidify and to cool. Mold handling equipment configurations include indexing lines, looping lines and mold car lines. Pouring of the metal can be accomplished automatically with a pouring furnace or transported to the molds in ladles. Ladle capacities can range in size from 100 pounds up to several tons.

After the metal in the mold has solidified and cooled, the mold is dumped onto a shakeout that separates the castings from the sand. The shakeout process can be performed with a wide variety of equipment. The casting is then desprued (separated from the runner system). The runner system is used to get metal into the casting cavity. The runner system is sent back to the melt department for reuse and the castings are sent to the finishing process. The sand is reused after it is screened and cooled. New sand is also added based upon a ratio of the amount of metal poured into a given quantity of sand. Casting finishing normally starts with shot blasting to remove sand that is stuck to the casting. The finishing area can be highly automated, using robots and Vision systems, or it can be a simple manually operated hand system. Normal types of finishing work include wheel grinding, belt grinding, trim press cutting, saw cutting, air arch cutting and hand grinding. Method used depends on the metal cast and the size of the casting.

4.7.1.2 Investment casting:

Investment casting is also known as the lost wax process. This process is one of the oldest manufacturing processes. The Egyptians used it in the time of the Pharaohs to make gold jewelry (hence the name Investment) some 4,000 years ago. Intricate shapes can be made with high accuracy. In addition, metals that are hard to machine or fabricate are good candidates for this process. It can be used to make parts that cannot be produced by normal manufacturing techniques, such as turbine blades that have complex shapes, or airplane parts that have to withstand high temperatures.

The mold is made by making a pattern using wax or some other material that can be melted away. This wax pattern is dipped in refractory slurry, which coats the wax pattern and forms a skin. This is dried and the process of dipping in the slurry and drying is repeated until a robust thickness is achieved. After this, the entire pattern is placed in an oven and the wax is melted away. This leads to a mold that can be filled with the molten metal. Because the mold is formed around a one-piece pattern (which does not have to be pulled out from the mold as in a traditional sand casting process), very intricate parts and undercuts can be made. The wax pattern itself is made by duplicating using a stereo lithography or similar model-which has been fabricated using a computer solid model master.

The materials used for the slurry are a mixture of plaster of Paris, a binder and powdered silica, a refractory, for low temperature melts. For higher temperature melts, sillimanite an alumina-silicate is used as a refractory, and silica is used as a binder. Depending on the fineness of the finish desired additional coatings of sillimanite and ethyl silicate may be applied. The mold thus produced can be used directly for light castings, or be reinforced by placing it in a larger container and reinforcing it more slurry.

Just before the pour, the mold is pre-heated to about 1000 °C (1832 °F) to remove any residues of wax, harden the binder. The pour in the pre-heated mold also ensures that the mold will fill completely. Pouring can be done using gravity, pressure or vacuum conditions. Attention must be paid to mold permeability when using pressure, to allow the air to escape as the pour is done.

Tolerances of 0.4 % of length are routinely possible, and as low as 0.14 % is possible for small dimensions. Castings can weigh from a few grams to 34 kg (0.1 oz to 80 lb), although the normal size ranges from 200 g to about 8 kg (7 oz to 14 lb). Normal minimum wall thicknesses are about 1 mm to about 0.4 mm (0.040-0.020 in) for alloys that can be cast easily.

The types of materials that can be cast are Aluminum alloys, Bronzes, tool steels, stainless steels, Stellite, Hastelloys, and precious metals. Parts made with investment castings often do not require any further machining, because of the close tolerances that can be achieved.

4.7.2 Analysis of Pelton Bucket

The model of Pelton bucket is developed in CatiaV4 for above discussed case study. This model is further used for analysis procedure. Different types of material are applied to the model and there corresponding weight is calculated using software only. The approximate cost required to manufacture this buckets with different materials is calculated by consulting the local manufacturer. The summary of weight and cost is presented in Table 4.3 as;

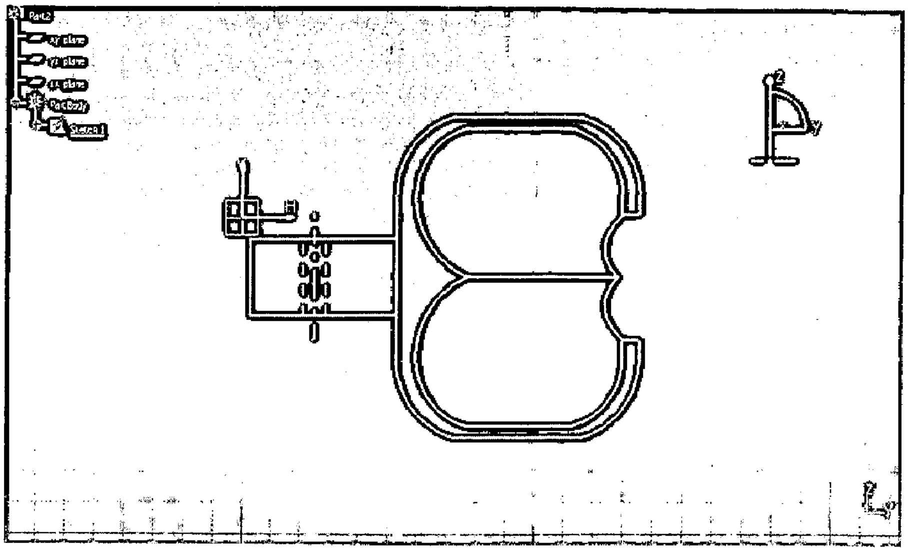


Fig 4.8: Pelton Bucket

Table 4.3: Cost and Weight for Different material bucket

	Aluminum	Bronze	Steel
Weight	6.4 kg	20 kg	19 kg
Approximate cost required to manufacture	Rs 4000/-	Rs 8000/-	Rs 12000/-

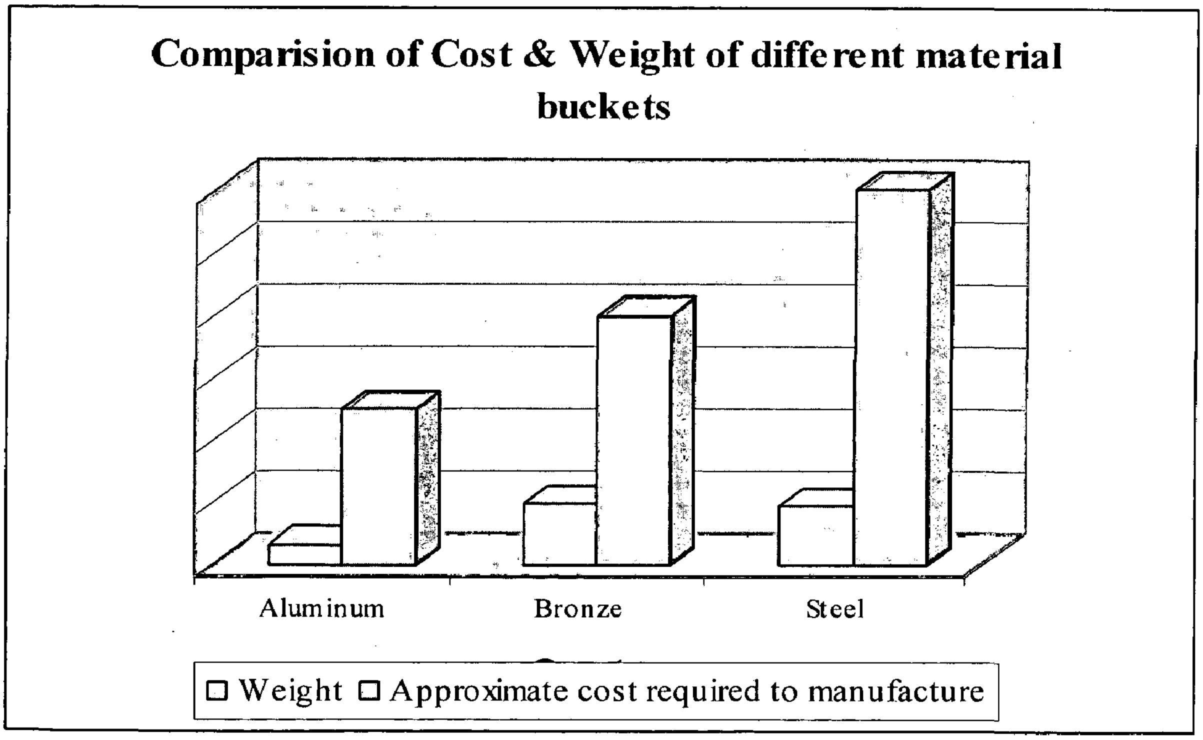


Fig 4.9: Comparison of Cost & Weight of different material buckets

4.8 DESIGN OF NOZZLE

The nozzle can be manufactured from a steel rod by machining on lathe, or it can be made from flat plate. The typical diagram of nozzle is shown in Fig4.10.

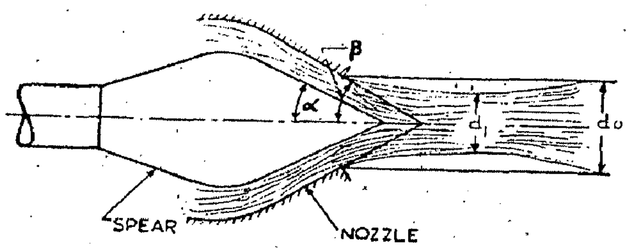


Fig 4.10:Schematic diagram of nozzle

Where,

α= angle of spear

β= angle of nozzle

d_0=diameter of nozzle

di= least diameter of jet

4.8.1 Diameter of nozzle

$$Q = \frac{3.142}{4 \times d^2 \times v_{jet}}$$

$$0.03624 = \frac{3.142}{4 \times d^2 \times 35.79}$$

d= 36.00 mm

The values of angle of spear and angle of nozzle taken as

$\alpha = 24^0$

$\beta = 42^0$

It is assumed throughout that jet and nozzle diameter are equal. In practice the jet diameter is marginally smaller but this difference can consider negligible for micro systems. The model of nozzle is developed in CatiaV4 for above discussed case study. This model is further used for analysis procedure. Different types of material are applied to the model and there corresponding weight is calculated using software only. The approximate cost required to manufacture this nozzle with different materials is calculated by consulting the local manufacturer. The summary of weight and cost is presented in Table 4.4 as;

Table 4.4: Cost and Weight for Different material nozzle

	Steel	Aluminum
Weight	4.7 kg	1.7 kg
Approximate manufacturing cost	Rs 3000/-	Rs 2000/-

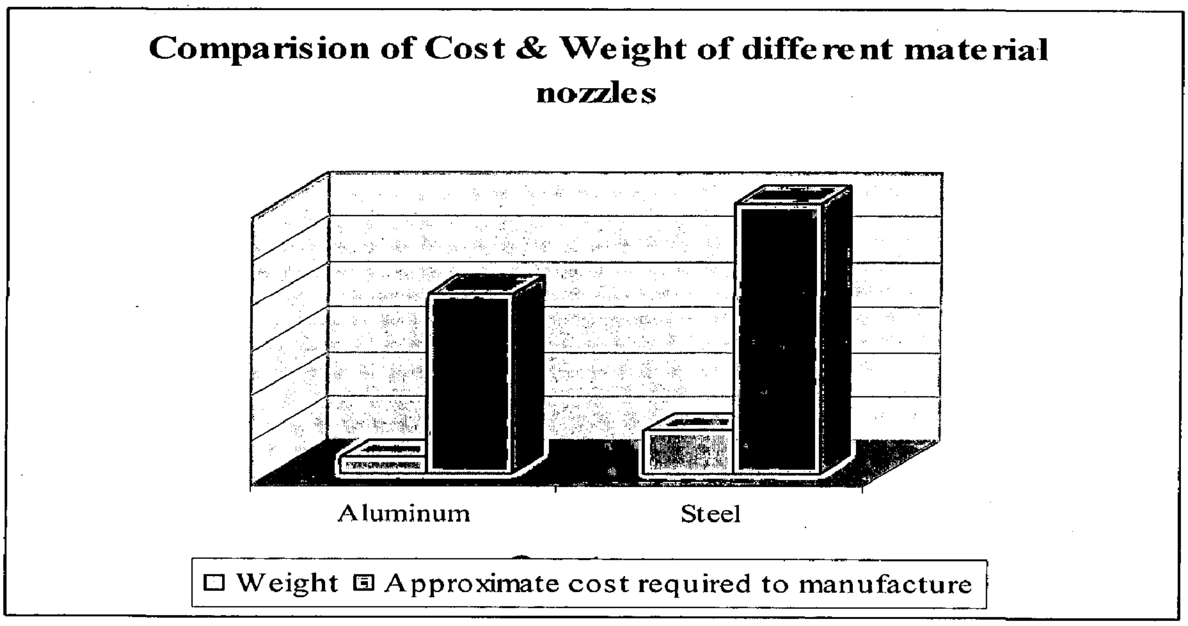


Fig 4.11: Comparison of Cost & Weight of different material nozzle

TECHNO-ECONOMIC STUDY WITH SURFACE ROUGHNESS

5.1 GENERAL

The critical components of micro hydro turbines from manufacturing point of view are runner and nozzle. They are contributing make cost of turbine. It has been found that for a optimally designed turbine, surface roughness especially in nozzle and turbine runner, play a dominant role in efficiency and cost of fabrication. It is therefore necessary to study this parts critically to create guidelines for local manufacturers for fabrication of small capacity turbines. Under this chapter analytic study has been carried out to establish relationship between the surface roughness, cost of fabrication. The cost of fabrication is taken by conducting survey for various fabrication processes of local manufacturers.

5.2 EFFECT OF SURFACE ROUGHNESS ON TURBINE EFFICIENCY

As with the flow in a pipe or over a flat plate, energy losses in turbo machinery depend on Reynolds number and relative surface roughness. The efficiency of the turbine thus affected by these parameters in various ways; it depends on size, viscosity and roughness. The energy losses in turbine consist essentially of head losses in hydraulic passages, volumetric as well as mechanical losses. Considering these basis it may be calculated that hydraulic and volumetric losses are scalable individually as function of the relevant Reynolds number and roughness of hydraulic passage.

The power delivered by turbine at shaft is given by useful power and all energy losses. Efficiency of turbine is given by the following expression,

$$\eta = \frac{P_t}{P_a} \qquad (1)$$

Where,

P_t is power developed by the turbine including all losses and

P_a is actual power available.

Further Eq(1) can be expressed in terms of known parameters as;

$$\eta = \frac{P_t}{9.81 \times Q \times H} \qquad (2)$$

Now power developed by turbine is calculated as follows

$$Pt = \frac{9.81 \times Q \times h}{\eta_{Vol} \times \eta_h \times \eta_{mech}} + P_M \qquad (3)$$

Where,

$\frac{9.81 \times Q \times h}{\eta_{Vol} \times \eta_h}$ is work done by the runner

P_M represents all mechanical losses of shaft seal and bearings.

η_{mech} is mechanical efficiency

η_{vol} is Volumetric efficiency which includes,

total quantity of water contained in the jet does not strike the bucket/runner and always there is some amount of water that slips and falls in the tail race without doing useful work. This loss is taken into consideration by volumetric efficiency. If ΔQ be the quantity of water lost on account of slip then it may be expressed as;

$$\eta_{vol} = \frac{Q - \Delta Q}{Q} \qquad (4)$$

η_h is Hydraulic efficiency which is written as considering the hydraulic losses of the turbine the hydraulic efficiency is written as

$$\eta_h = \frac{H - \Delta H}{H} \qquad (5)$$

The hydraulic losses in nozzle and runner/bucket are made up by scalable (friction) losses which depends on Reynolds number and surface roughness and by losses created by exchange of momentum whenever the velocity distribution is non uniform. Such non uniformities are caused by the work transfer from the buckets/runner, deceleration of the fluid.

Putting values of Eq. (3) in Eq (2) we may get the expression as;

$$\eta = \frac{\dfrac{9.81 \times Q \times H}{\eta_{vol} * \eta_h} + P_M}{9.81 \times Q \times H} \qquad (5)$$

$$\eta = \frac{1 + \eta_{vol} \times \eta_h \left(\dfrac{P_M}{P_a} \right)}{\eta_{vol} \times \eta_h} \qquad (7)$$

$$\eta = \frac{1}{\eta_{vol} \times \eta_h} + \frac{P_M}{9.81 \times Q \times H} \qquad (8)$$

The quantities η_{vol}, η_h, depends on the Reynolds number and surface roughness. The term $\frac{P_M}{9.81 \times Q \times H}$ may be considered as constant in this case..

Therefore,

$$\eta = \frac{1}{\eta_{vol} \times \eta_h} \qquad (9)$$

This generalized form of efficiency is in terms of surface roughness, the same may be obtained for different turbines by incorporating their parameters which has been discussed as follows.

5.2.1 For Pelton turbine

In Pelton turbine water is coming from nozzle and striking on the bucket which in turn drives the turbine shaft. Thus potential energy in water is converted into kinetic energy. The main parts in which losses can occur are nozzle and wheel. The generalized form of efficiency derived earlier may be modified by considering followings;

- The maximum efficiency of Pelton wheel is represented by the following expression. [22]

$$\eta_w = \frac{2u(v_1 - u) + (1 + \dfrac{\cos\beta_2}{\sqrt{1+k}})}{v_1^2} \qquad (10)$$

Where,

u is circumferential velocity of wheel

v_1 is velocity of jet

k is coefficient taking account of friction losses in flow through bucket.

$\cos\beta_2$ is bucket exit angle.

This equation contributing volumetric efficiency and part head efficiency.

- Losses in nozzle it may be estimated by using following expression[23]

$$\eta_h = 4\, K_{u1}\,(K_{v1} - K_{u1}) \qquad (11)$$

Where,

K_{u1}, K_{v1} = coefficient of velocity

This loss compromises the loss due to water flow through pipe and contraction of nozzle at the opening. The losses in pipe (h_f) is calculated by formula [24]

$$h_f = \frac{4 \times f \times L \times v^2}{d \times 2 \times g} \qquad (12)$$

Where,

f is friction factor

Lis length of pipe

v is velocity of jet

d is diameter of pipe

g is acceleration due to gravity

Head loss due to contraction of nozzle (hc) is given by,

$$h_c = k\,\frac{v^2}{2 \times g} \qquad (13)$$

Therefore total loss in nozzle is in terms of friction factor estimated by the expression given below

$$\eta_h = k \times f \qquad (14)$$

Putting values of (10) and (11) in equation (9) we get efficiency as;

$$\eta = \frac{1}{2u(v_1 - u) + (1 + \frac{\cos\beta_2}{\sqrt{1+k}}) \times 4K_{u1}(K_{v1} - K_{u1}) \times f} \quad (15)$$

By keeping u, v_1, $\cos\beta_2 = 180^0$, L, v2, d as constants, the above expression can be modified as;

$$\eta = K^* \frac{1}{(1 - \frac{1}{\sqrt{1+f}}) * f} \quad (15)$$

$$\eta = K^* \frac{1}{f\ (1 - \frac{1}{\sqrt{1+f}})} \quad (17)$$

$$\eta\ \alpha\ \frac{1}{f\ (1 - \frac{1}{\sqrt{1+f}})} \quad (18)$$

The expected variation in efficiency of Pelton turbine due to friction factor f is estimated by using above relation and this trend of variation in efficiency can be seen in Fig 5.1.

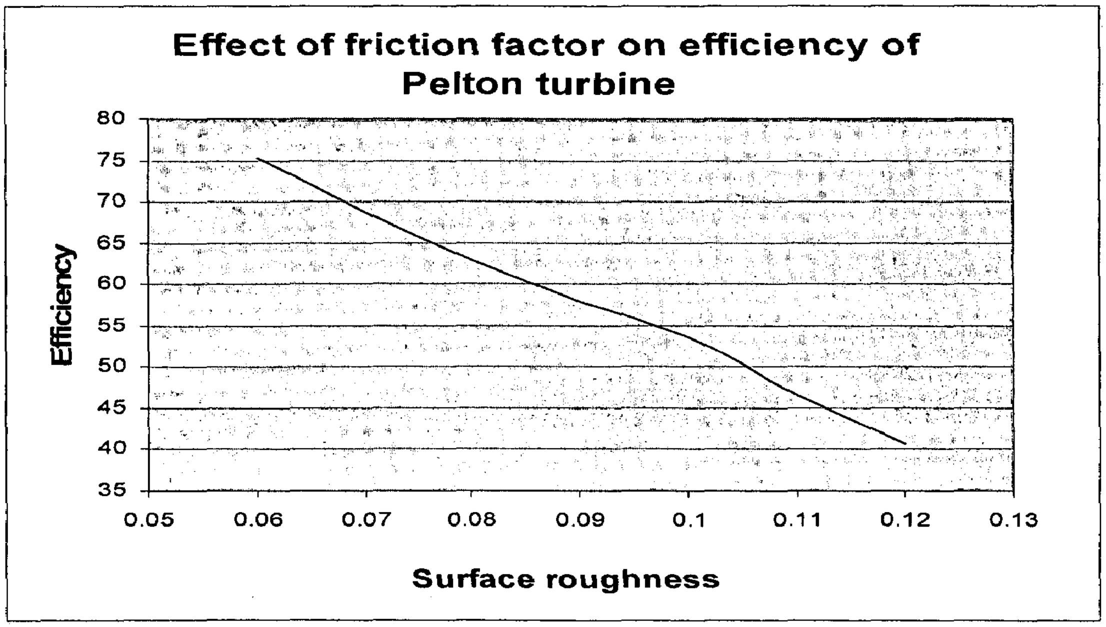


Fig 5.1: Effect of friction factor on efficiency of Pelton turbine

5.2.2 For Cross flow turbine

The cross flow turbine consists of two parts, a nozzle and turbine runner. The runner is built of parallel circular disks joined together at the rim with a series of curved blades. The nozzle is in rectangular shape. The water strikes the blade on the rim of the wheel, flows over the blade, leaving it, passing through the empty space between the inner rims, and discharge at the outer rim. The losses will occur in the nozzle and runner.

Maximum efficiency of cross flow turbine is given by following expression [25]

$$\eta_{max} = (2C^2 \frac{u}{v_1}) \times (1 + \frac{\varphi \cos\beta_2}{\cos\beta_1}) \times (\cos\alpha_2 - \frac{u}{v}) \qquad (19)$$

Where,

C is factor depends on nozzle

Φ is coefficient of velocity

u is peripheral velocity

v is velocity of jet

β_1 ,β_2 are blade angle.

This equation contributes volumetric efficiency and hydraulic efficiency.

The equation (9) can me modified as;

$$\eta = \frac{1}{(2C^2 \frac{u}{v_1}) \times (1 + \frac{\varphi \cos\beta_2}{\cos\beta_1}) \times (\cos\alpha_2 - \frac{u}{v})} \qquad (20)$$

By keeping all the parameters of turbine constant the efficiency of turbine in terms of friction factor is given as follows;

$$\eta = K \times \frac{1}{f^2(1+f)} \qquad (21)$$

$$\eta \propto \frac{1}{f^2(1+f)} \qquad (22)$$

The expected variation in efficiency of Cross flow turbine due to friction factor f is estimated by using above relation and this trend of variation in efficiency can be seen in Fig 5.2. The friction factor range is given for this formula is 0.12 μm to 0.5 μm.

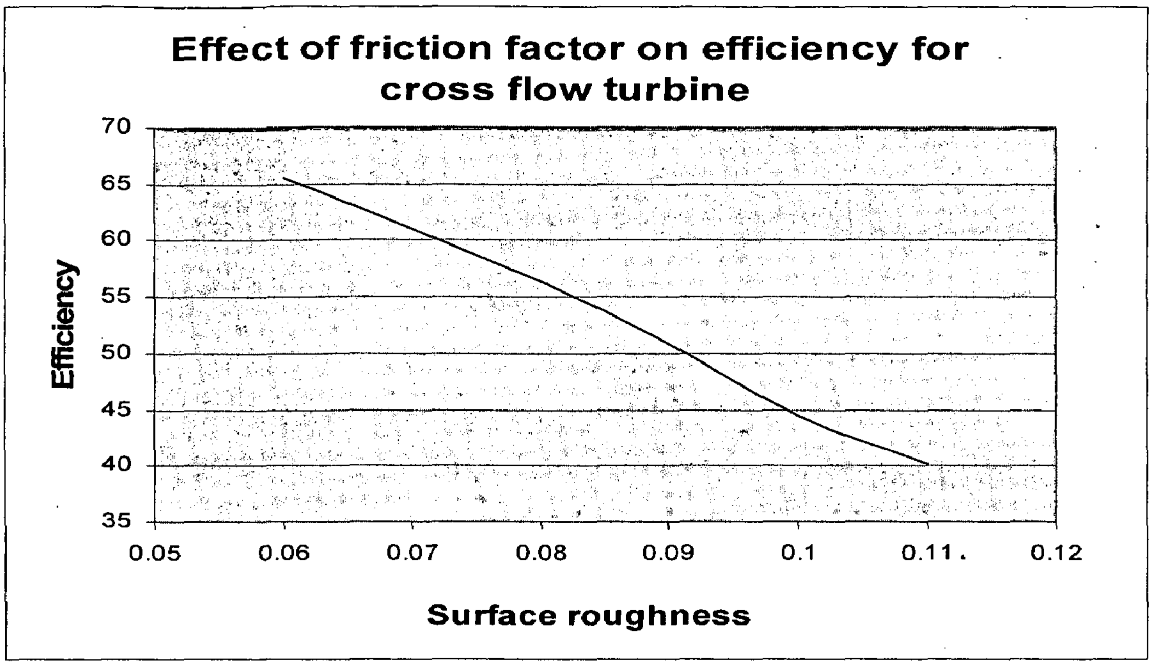


Fig 5.2: Effect of friction factor on efficiency of Cross flow turbine

The surface can be improved by various manufacturing processes or surface coating to have the following advantages

- The various friction losses, hydraulic losses and mechanical losses are reduced which are contributing towards the improved performance and efficiency of a turbine as discussed above.
- The smooth surface last longer resulting into better efficiency and longer mean time to repair.
- Component will remain safe due to coating on it.
- Cost required to improve surface finish can be justified in terms of greater efficiency and increase in life or mean repair time.

The processes to provide smooth surface are discussed below

5.3 SURFACE FINISHING PROCESSES

5.3.1 Mechanical surface finishing processes

In order to estimate the cost of surface finishing of turbine components to minimize the losses, various processes available in the literature are essential to discuss.

5.3.1.1 Grinding and Polishing

Surface finish can be improved by manual grinding and polishing. Depending on the initial conditions it is possible to reduce the roughness v. The specification adopted for grinding is the grain of the grinding medium. The roughness is reduced in stages (grain 40, 80, 120, 180, 240, 400). In most instances there is a predictable relationship between grain size and the roughness value to be realized.

Polishing is a treatment that is generally carried out with so-called polishing pastes. The area of application is comparable to that of electrolytic polishing. Mechanical polishing of stainless steel may due to forcing of polishing paste into the surface result in that surface no longer being suitable for specific applications: pharmaceutical, medical and food industry.

5.3.1.2 Abrasive Blasting

Abrasive blasting involves directing a high-pressure stream of air and free abrasive particles at the surface of a work piece. “Starblast” has a coarse, angular grain shape, and is very effective for removing rust and welding scale from steel work pieces. It is generally too coarse for use on aluminum or plastics. Glass beads are finer in size and smooth in shape. They produce a non-directional, matte surface on aluminum. It is important to use the lowest air pressure that will pick up the media when glass bead blasting It is important to remove any wax, oil or grease from the surface before abrasive blasting so that those contaminants don’t become driven into the surface by the blasting

5.3.1.3 Buffing

Buffing is normally done with power. A cloth buffing wheel is coated with very fine abrasive (Tripoli, rouge, etc.) which is applied from a wax stick to the rotating perimeter of the wheel. The work piece is then placed in contact with the edge of the buffing wheel and moved so that the entire surface to be buffed is covered. The result is a highly lustrous surface. Buffing technique is critical.

5.3.1.4 Filing

Filing is done to establish geometry and refine surface finish. It is generally a higher material removal rate process than sanding. Files come in a wide variety of shapes and degrees of coarseness. Common shapes include round, flat, square, 3 square and half-round. Coarseness ranges from "coarse" (very heavy cuts) to medium cut to "smooth" (fine cuts). Files come in large (10 or 12") and small sizes . Filing technique is important and includes 1) use a sharp file, 2) use a "file card" to keep the gullets between file teeth free of debris, and 3) bear down on the file only during the forward stroke. "Draw filing" and "chalking" the file are techniques to achieve smooth surfaces. Filing is more successful when the work piece can be held in a vise .

5.3.1.5. Sanding

Sanding is done to make a surface more consistent, smoother, or to remove machining marks, or to establish "grain" (directionality). "Wet or dry" sandpaper (liquid resistant sheets with silicon carbide abrasive)can be used for best results. Grit sizes range from 50 (and lower) which is very coarse to 500 (and higher) which is very fine. Use light oil, kerosene or water as a sanding fluid. Sanding can be done by hand or by power. Sanding techniques include contour block sanding, straight edge reference sanding, and cross sanding, and power sanding on the lathe. Usually hand sanding or lathe power-sanding result in much better quality results.

5.3.2 Surface Coating Processes

5.3.2.1 Anodizing (Purchased Service)

Anodizing is the electrolytic treatment of aluminum that forms a very thin coating of aluminum oxide on the surface of the work piece. The oxide coating is of an open cell structure which is naturally gray (roughly aluminum color) but can be dyed a wide range of colors. The coating is very hard (aluminum oxide is a very hard ceramic material), and does not conduct electricity. Anodizing is either "conventional" or "hard". Conventional anodizing creates a film thickness which is so thin that it will not change interference or thread fits. Conventional anodizing makes the surface much more scratch resistant and durable than natural aluminum and offers a very wide range of possible colors. Anodizing appearance (color and reflectivity) is very specific to the alloy of aluminum being anodized.

5.3.2.2 Electroplating (Purchased Service)

Plating adds a thin coating of metal to the surface of the work piece. The work piece must be electrically conductive Plating materials include chrome, nickel, silver and gold. Colors range from black to chrome. Surface reflectivity can be very glossy or semi-matte. Typically the coating is very scratch resistant. The work piece must generally be delivered with the surface finished to the same degree of luster and refinement that is desired in the plated part. This means that a great deal more time would be spent preparing a surface for chrome plating than for powder coating. It is possible but expensive to electroplate aluminum. This process is normally used on steel, brass, or copper.

5.3.2.3. Powder Coating (Purchased Surfaces)

Powder coating creates a thin (about 0.002 of an inch per coat), even coating of plastic on the part. The resulting surface can be very glossy, matte. A very wide range of colors is available. Common power coating resins include epoxy, polyurethane, polyester, and acrylic. The process involves thermal fusion of a thin layer of plastic powder that is attracted to the surface of the work piece by electrostatic charge. This means that the work piece must be able to withstand the heat of fusion (typically about 400°F). Powder coating is suitable for steel, and aluminum and is a better alternative than anodizing aluminum castings or weldments. .

5.4 EFFICIENCY AND COST VARIATION WITH THE SURFACE ROUGHNESS

For typical sizes of Pelton and cross flow turbines an analytical study has been carried out to analyze the effect of surface roughness on cost and efficiency of the turbine.

5.4.1 For Pelton turbine

The effect of surface finish on performance on Pelton turbine and effect on cost is analyzed in following manner

5.4.1.1 Size/ specification of turbine

The size of turbine is given to turbine manufacturer. The specifications of turbine that is its runner diameter, bucket diameter, number of buckets, nozzle diameter etc are given which are discussed previously in Chapter-4.

5.4.1.2 Components of turbine considered

Once the turbine dimensions have been fixed, next thing is to identify the components which are most critical to surface finish and efficiency. In the case of Pelton turbine the most critical components are nozzle and buckets. Majority of hydraulic and volumetric losses are occurred in these parts. So, main focus is given to manufacture these components.

5.4.1.3 Sources of the cost obtained

The component list along with dimensions is given to few of the manufacturers. And the cost and expected efficiency of the final product is collected from them., which included the special attention towards critical components. The manufactures are "Geeta pumps. Saharanpur", " Diwan Enterprises, Roorkee", " Kirloskar Brothers Ltd, Pune".

5.4.1.4 Results and discussion

The effect of surface roughness on efficiency of Pelton turbine is given in the Eq.18 and it is represented in Fig 5.1 Same trend is observed in the actual practice also. The various values of surface roughness, cost required to manufacture and its corresponding efficiency is given in Table 5.1.

Table 5.1: Surface roughness, cost of manufacturing and corresponding efficiency for Pelton turbine

Sr no	Surface roughness(μm)	Cost required to manufacture turbine(Rs)	Efficiency (%)
1	0.12	18000	40
2	0.08	20000	55
3	0.07	22000	55
4	0.05	24000	70
5	0.04	25000	70

The relation between surface roughness Vs efficiency, surface roughness Vs cost and variation of cost and efficiency with respect to surface roughness in shown in Fig5.3, Fig.5.4 and Fig 5.5 respectively.

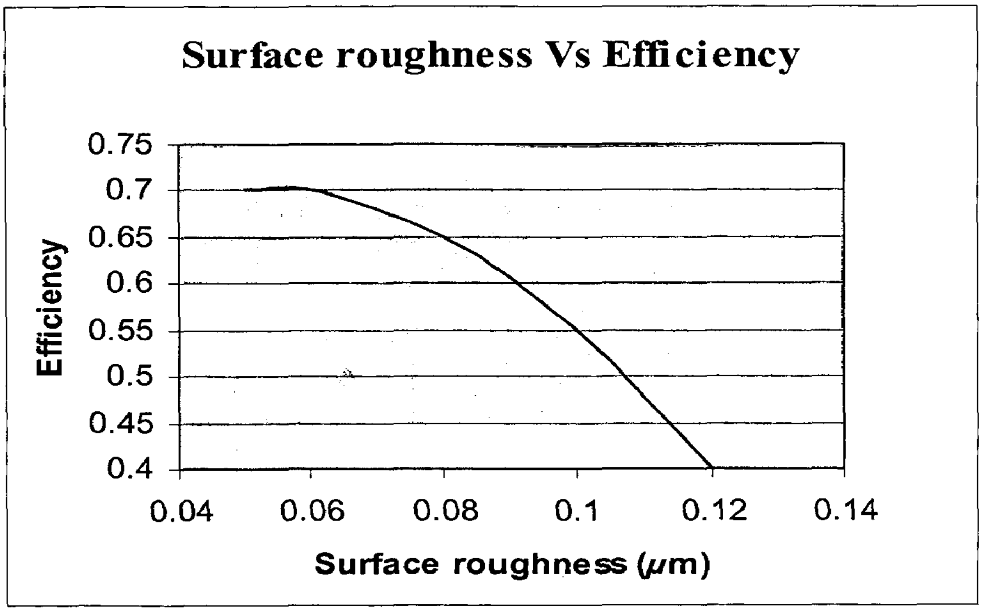


Fig 5.3: Variation of Efficiency with respect to surface roughness

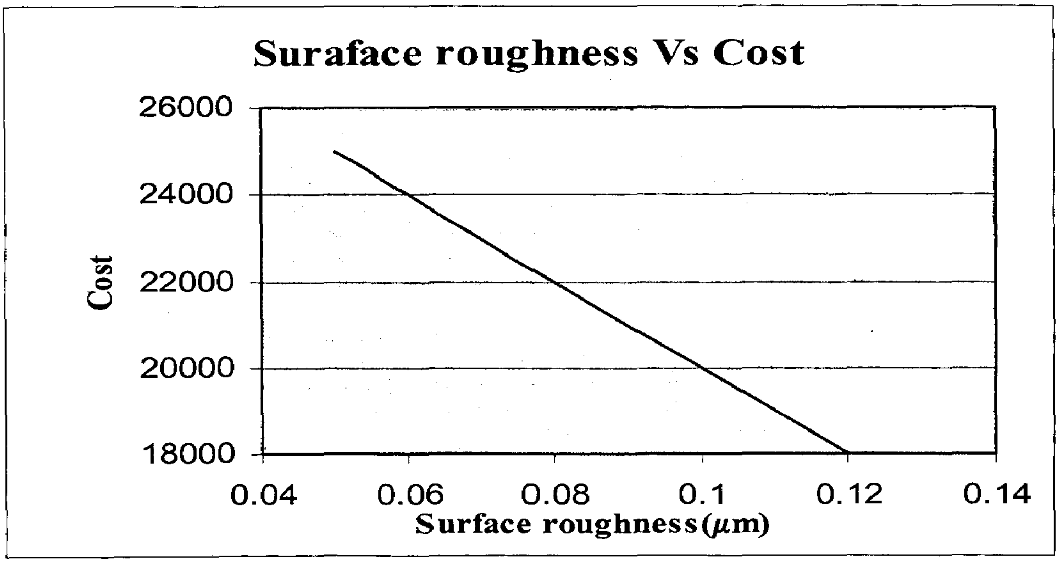


Fig 5.4: Variation of cost with respect to surface roughness

Fig 5.3 shows the efficiency variation with the surface roughness, it has been observed that with the considered turbine maximum efficiency could be achieved up to 70 %.

Fig 5.4 shows variation in fabrication cost with surface roughness. The plot has been prepared by taking the base cost for turbine as Rs 18000/-. The trend shows that the cost increases sharply with the smoothness of the surface.

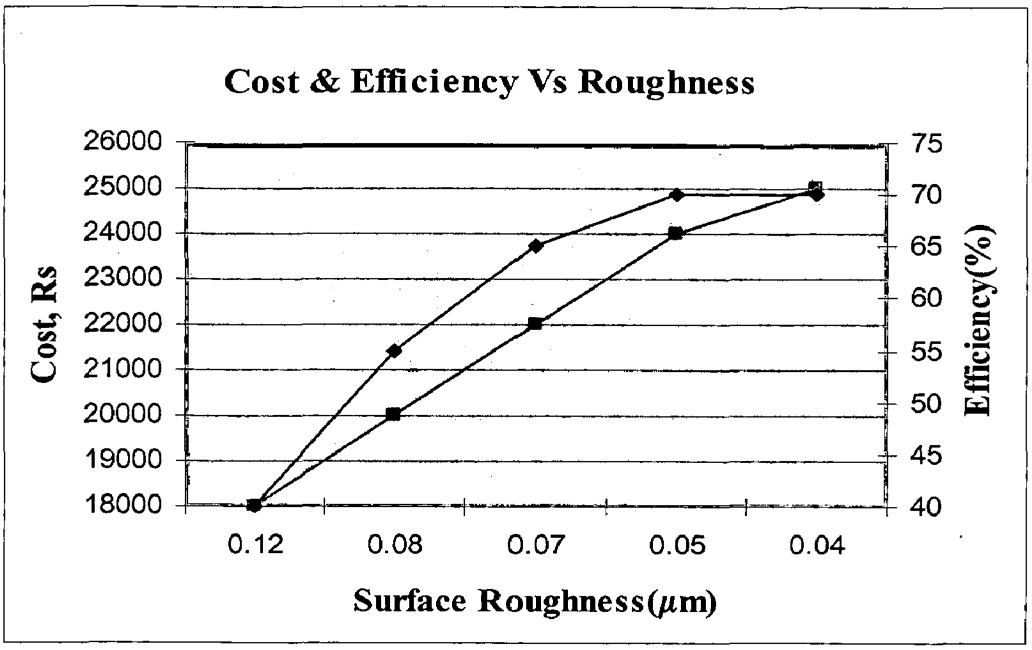


Fig 5.5: Variation of cost & Efficiency with respect to surface roughness

Composite curve has been prepared and shows in Fig. 5.5 to compare the cost and efficiency with the surface roughness. It has been observed that for a typical size of turbine considered the break even point in the efficiency is achieved at 70%.

5.4.2 For Cross Flow turbine

On similar basis analysis of cross flow turbine is carried out. The effect of surface roughness on efficiency of Cross Flow turbine is given in the Eq.22 and it is represented in Fig5.2. Same trend is observed in the actual practice also. The various values of surface roughness, cost required to manufacture and its corresponding efficiency is given in Table 5.2

Table 5.2: Surface roughness, cost of manufacturing and corresponding efficiency for cross flow turbine

Sr no	Surface roughness(μm)	Cost required to manufacture turbine(Rs)	Efficiency (%)
1	0.12	12000	40
2	0.10	14000	52
3	0.08	16000	60
4	0.06	18000	65
5	0.05	19000	65

The relation between surface roughness Vs efficiency, surface roughness Vs cost and variation of cost and efficiency with respect to surface roughness in shown in Fig5.6, Fig.5.7 and Fig 5.8 respectively.

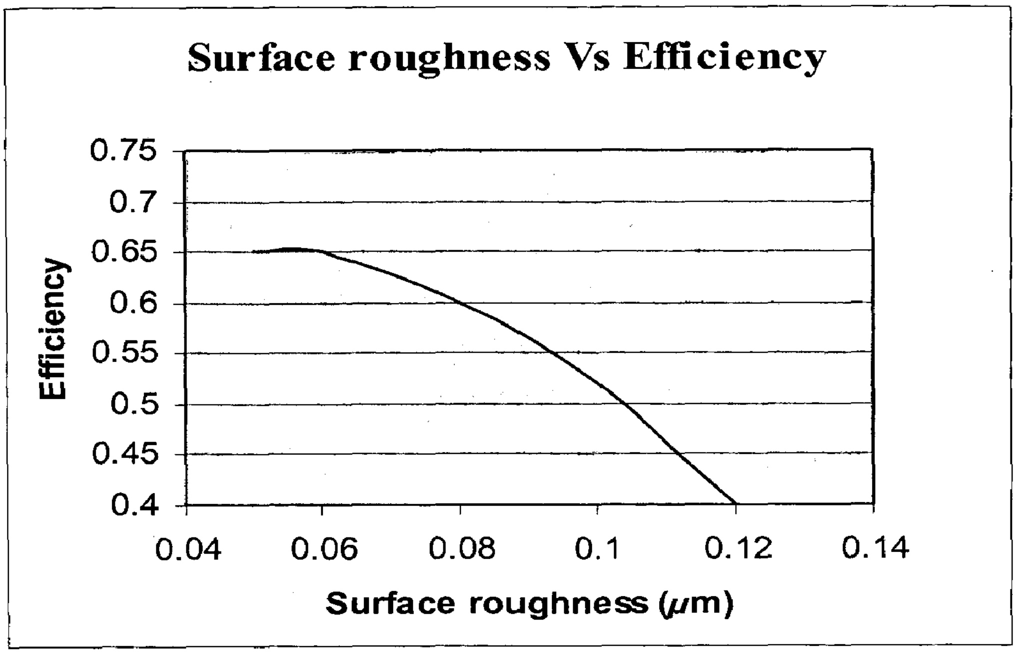


Fig 5.6: Variation of Efficiency with respect to roughness

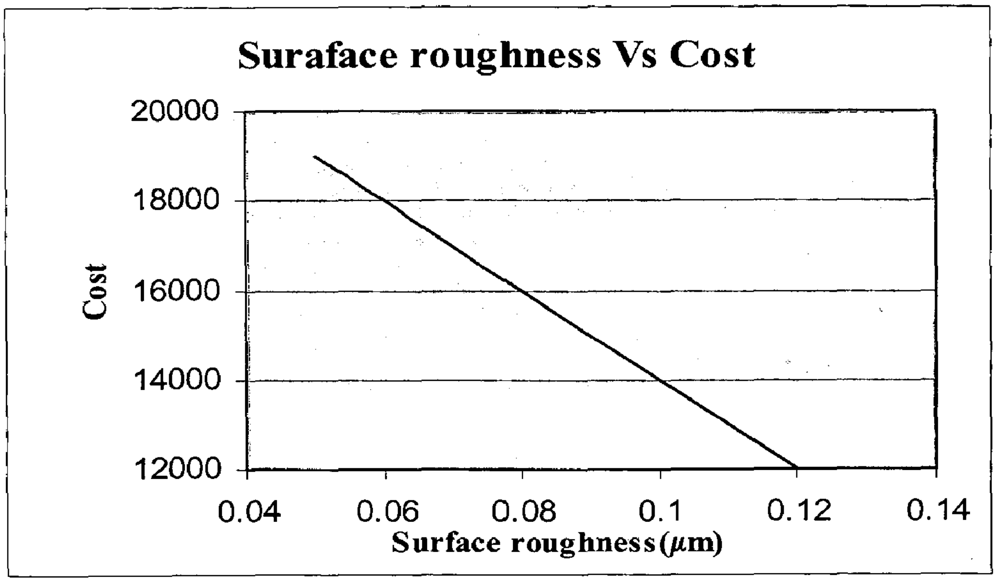


Fig 5.7: Variation of cost with respect to roughness

Fig 5.6 shows the efficiency variation with the surface roughness, it has been observed that with the considered turbine maximum efficiency could be achieved up to 65 %.

Fig 5.7 shows variation in fabrication cost with surface roughness. The plot has been prepared by taking the base cost for turbine as Rs 12000/-. The trend shows that the cost increases sharply with the smoothness of the surface.

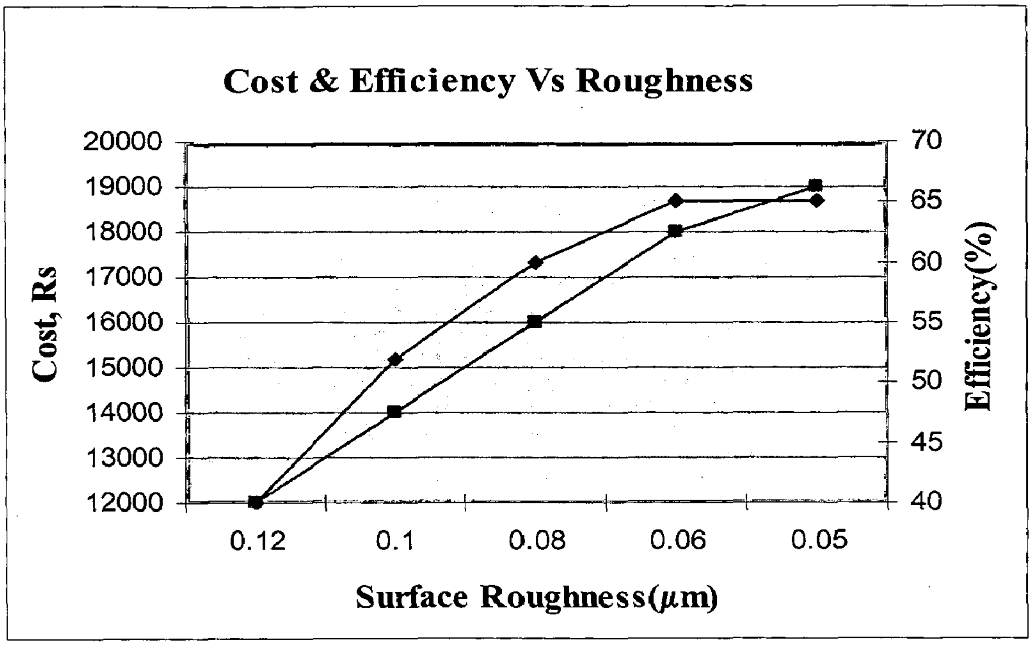


Fig 5.8: Variation of cost & Efficiency with respect to roughness

Composite curve has been prepared and shows in Fig. 5.8 to compare the cost and efficiency with the surface roughness. It has been observed that for a typical size of turbine considered the break even point in the efficiency is achieved at 65%.

CONCLUSIONS AND RECOMMENDATIONS

Lot of potential exists in the range of micro hydro and is ready to be harnessed. But development of micro hydro power plants has not been encouraging in past due to their high cost. Major part contributing towards cost is hydro turbines. There is no standard procedure available for manufacturing micro hydro turbine, mostly are manufactured by local manufacturers and their efficiency is low. In view of the above, the present study had been carried out to discuss various manufacturing processes in order to improve the efficiency-cost ratio of small capacity turbines in the range of micro hydro. Following conclusions are drawn from the study.

6.1 CONCLUSIONS

i. Various types of turbines are studied with respect to micro hydro range (capacity less than 30 kW) and it has been found that Pelton turbine. Cross flow turbine, Turgo impulse turbine are best suited for given range

ii. The manufacturing procedures used by industry for manufacturing of turbines have been studied and their suitability for micro hydro turbines has been checked.

iii. The possible materials for manufacturing of micro hydro turbines have been identified. It has been found that aluminum, bronze and steel are best suited materials for various parts of micro hydro turbines.

iv. A cost analysis for, manufacturing process suitable in this range of hydro turbine is carried out which could be beneficial to micro hydro power plants.

v. The parts which are having direct impact on turbine efficiency and cost are identified. It has been found that runner and nozzle are most critical parts.

vi. Effect of surface roughness on turbine efficiency has been studied; it has been found that an increase in surface finish that is if we increase surface roughness value from 15 μm to 5 μm, that results into increase in turbine efficiency in the range of 40-70%.. Increase in cost due to surface finish process can be justified in terms of increased in efficiency, increase in life cycle and reduced maintenance. Further decrease in surface roughness will not increase the efficiency but cost will increases substantially.

6.2 RECOMMENDATIONS

The manufacturing cost of micro hydro turbine can me reduce by adopting manufacturing processes available locally but efficiency has to be compromised. But by identifying critical components for turbine, such as runner and nozzle in case of micro hydro turbines and providing little attention while manufacturing it, we can get increased efficiency. Surface finish of this identified parts can results into increase in performance of turbine. So it is recommended while manufacturing proper processes must be used to get increased efficiency at low cost.

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