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DESIGN AND MANUFACTURING PROCESS OF SMALL SCALE WATER TURBINE BY USING RPRT FOR ENERGY HARVESTING

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ABSTRACT:

Natural resources like river, stream, waterfall can be used for the generation of power. In this the horizontal axis impulse turbine is designed in which water jet is impulsed which strikes tangentially on the integrated vanes or rotor. Turbine designing is for small applicatiom, where limited power is generated which can be uitilised for lighting a power bulb or for battery charging. Working on this topic resulted into design & manufacture of the small scale low cost & low weight turbine, for which rapid prototype manufacturing technique is used and suggested. Turbine manufactured by RP technique is not suitable for commercial use but for small applications in remote aresa where reach of electrification grid is impossible.

KEYWORDS: RP, Energy harvesting, Design & manufacture, turbine design.

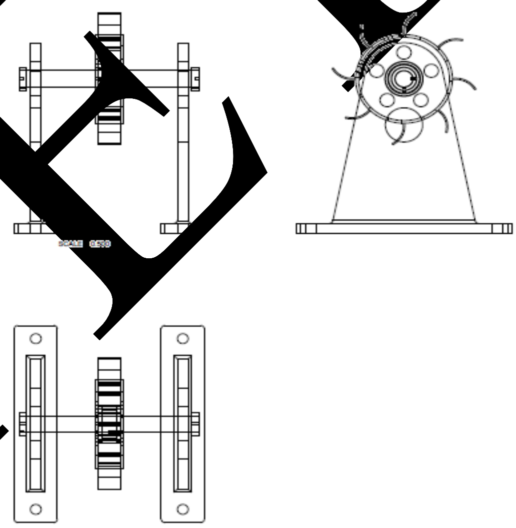
I.INTRODUCTION:

Small scale water turbine which is also known as microhydro power turbine. micro hydro turbines are developed from last centuries back. Means the use of natural water source for the power generation is a old technique exist. In this work, new design of turbine alongwieth new and low cost, low weight manufacturing technique is introduced. Also anlysis of the turbine vane is done.

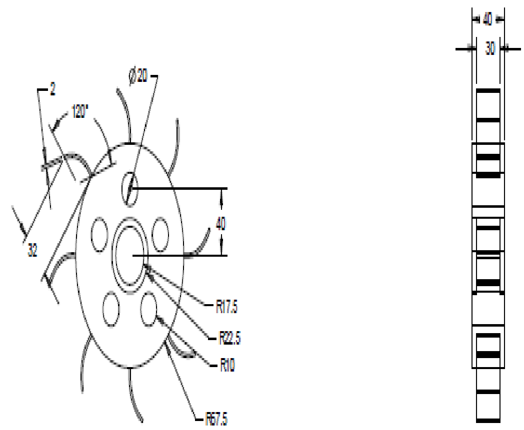
II.DESIGN FOR THE TURBINE PROTOTYPE:

Very initial consideration for the microhydro turbine is limited space availability ranging from 1 to 5 feet for installing that designed turbine. Accordingly limitations are kept to the sizes of the turbine parts.

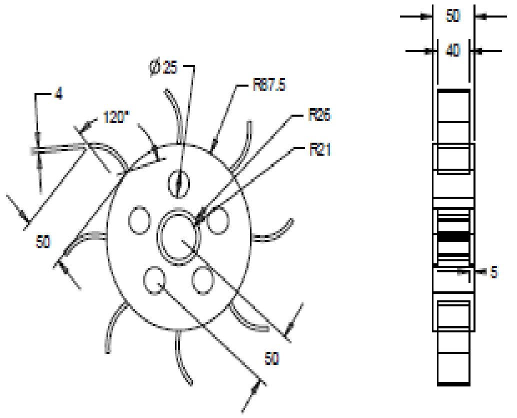
A. 2D DIAGRAMS OF ALL DESIGNED PARTS:



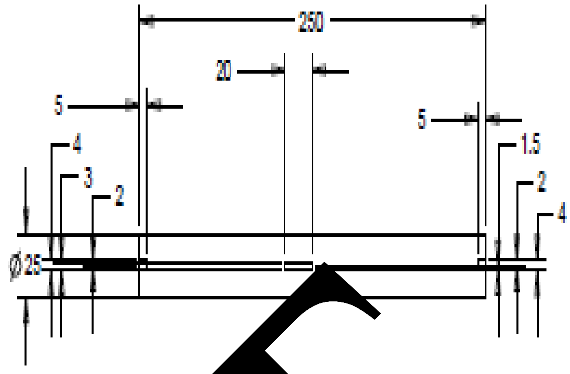
Turbine assembly drawing

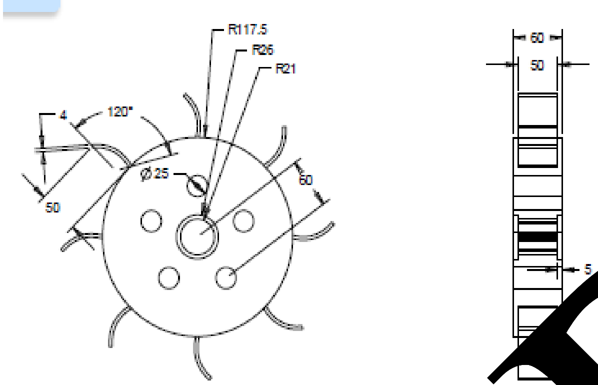


Rotor1 (Diameter 135)

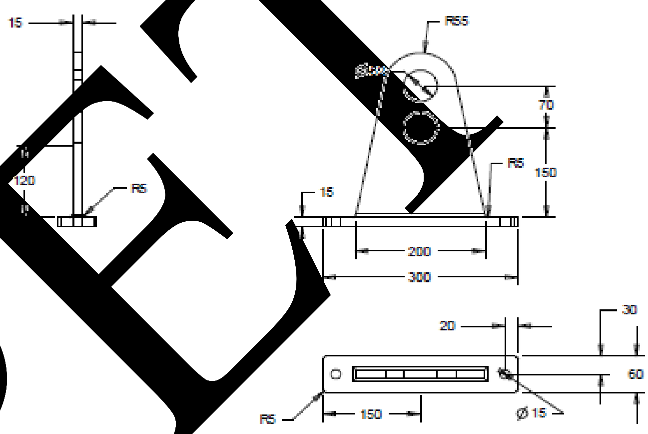


Rotor2 (diameter 175)

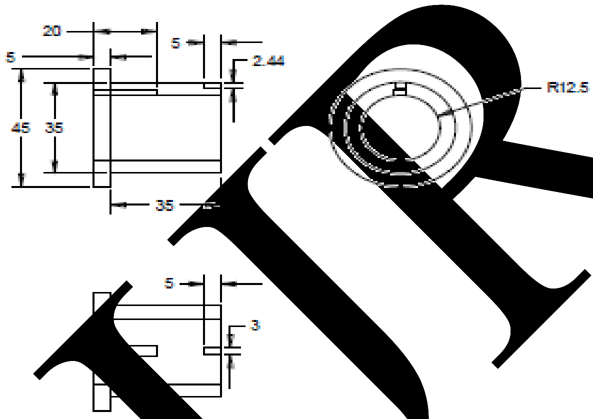




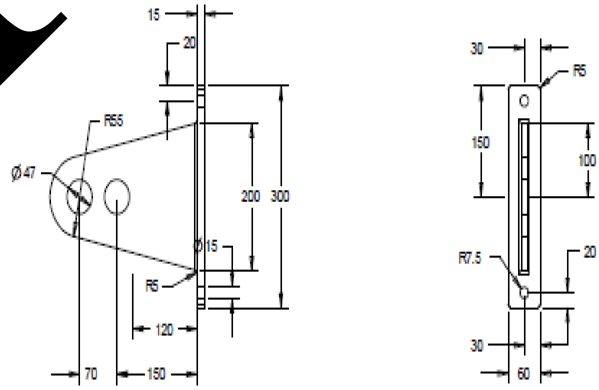
Rotor3 (Diameter 235)



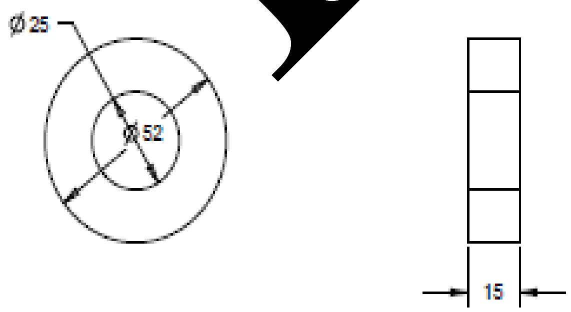
shaft



Insert



Stand2



Ring

III.PARTS GEOMETRIES WITH DIMENSIONS:

1) Vanes (integrated) circular subtended angle is kept 120^0 with height 32mm & depth 10 to 12mm.
2) Rotor-135mm, 175mm and 225mm diameter.
3) $D_p =$ $Pitch\ diameter(considering\ integrated\ vanes)of\ the\ roto$ $150, 200\ and\ 250mm$
4) No of blades-08.
5) Insert, which is fitted into rotor, through which shaft is passing, dimension is

$45 \times length\ 45$.

6) Bearings –two types

a. Ball bearing-NO 1205-Inner Diameter 25, outer diameter-52, width 12mm.

b. Cylinderical roller bearing no-16005, Inner diameter 25, outer diametere 47, width 08mm.

7) Flow velocity $V_f = 1, 1.5, 2, 2.5\ and\ 3\ m/sec$

8) N rotational speed of the rotor= limit 150 to 430rpm.

9) Net head $H_n = 1\ feet\ to\ 5\ feet$.

10) Gravitational accleration g=9.81m/sec^2

11) $Q = flowrate\ of\ waterstream = minimum\ 0.0176 \frac{m}{sec^3}, maximum\ 0.1472 \frac{m}{sec^3}$.

12) $R_L = Length\ of\ the\ rotor = 45mm$

13) $B_C = chord\ of\ the\ blade$

14) $\omega = rotational\ speed\ of\ the\ rotor = \frac{2\pi N}{60}$

15) $RPM\ of\ Rotor = 38.6 \times \sqrt{H_n/D_r}$

16) $V_F = Impact\ velocity\ of\ water$.

17) $\theta = angle\ of\ blade = subtended - 120°$

IV.DESIGN STEPS:

(from design of high efficiency cross flow turbin[illegible] hydropower plant by Bilal Nasir)

A) The design procedure of the ***cross-flo[illegible]ine*** involves the **following steps:**

1. Preparing the site data

This involves the calculations and [illegible]ring the net head of the hydro-power plant an[illegible]ts wa[illegible]w rate.

a. Calculation of the [illegible]d (Hn):

$H_n = H_g - H_f$ ([illegible]n)

(1)

Where,

Hg = the gross head w[illegible] was the ve[illegible] distance between w[illegible]ater surface lev[illegible] the intake [illegible]at the turbine[illegible]s distance can b[illegible]easured b[illegible] modern electronic [illegible]l levels.

Hf = total he[illegible]sses due to the o[illegible]en channel, trash rack, intake, pe[illegible]k and gat[illegible]alue. These losses were approximately [illegible]l to 10% of gross head.

b. Calculation o[illegible]ter flow rate (Q):

The water flow rate can b[illegible]lculated by measuring river or stream flow velocity (Vr) and river cross-sectional area (Ar),

then:

$Q = V_r \times A_r \quad (m^3/sec)$

(2)

2. Calculation of turbine power (Pt)

The electrical power of the turbine in Watt can be calculated as:

$P_t = Q \times H_n \times \rho \times g \times \eta_h \quad (W)$

(3)

Where:

Q discharge [m3/s]

Hn gross head [m]

ηh hydraulic efficiency [-]

ρ water density [kg/m3]

g gravitational acceleration [m/s^2]

FOR FURTHER CALCULAT[illegible]N:

Following are the known[illegible]alues

ρ = 1000kg /m^3

g = 9.81m/ s^2

Consider, η_h = [illegible].85%

3. Ca[illegible]lation of turbine efficien[illegible]t)

Th[illegible] maximum turbine efficiency ca[illegible]alculated as: [illegible]6]

η [illegible] $\times C^{2\times}$([illegible] $+ \psi) \times \cos$ [illegible]$(\propto)$

wher[illegible] blade roughnes[illegible]oefficient (0.98)

(4)

[illegible]rom above [illegible]tion, i[illegible]s clear that for maximum turbine [illegible]fficiency, the a[illegible] angle (α) should be kept as small as possible .

4. Calculation of the turbine speed (N):

The correlation between specific speed (N_s) and net [illegible]ead H_n is [illegible] for the cross-flow turbine as following,

$N_s = \frac{513.25}{Hn^{0.505}}$

(5)

Also the specific speed in terms of turbine power in Kw, turbine speed in (r.p.m) and net head in (m) is given as , [9]

$N_s = N \times \frac{\sqrt{Pt}}{Hn^{1.25}}$

(6)

From above equations (5) and (6) , the turbine speed can be calculated as:

$N = 513.25 \times H_n^{0.745} / \sqrt{Pt}$(rpm)

(7)

5. Calculation of runner outer diameter (D_o)

At maximum efficiency, the tangential velocity of the runner

Outer periphery is given as [26]

$Vt_r = \frac{1}{2} \times C \times (\sqrt{2 \times g \times H_n})(\cos \propto)$

(8)

Also as we know,

$V_{tr} = W \times \frac{D_o}{2} = 2\pi N D_o/120$
(9)

By comparing eq. (8) & (9) the runner outer diameter can be calculated as :

$D_o = 40 \times \frac{\sqrt{Hn}}{N}$ (m)
(10)

6. Calculation of blade spacing (S_b):

The thickness of jet entrance t_{je}measured at right angles to
the tangential velocity of runner is given as [26]

$t_{je} = k \times D_o$ (m)
(11)

Where K = constant = 0.087

The tangential blade spacing (Sb) is given as[26]

$S_b = \frac{t_{je}}{\sin\beta 1} = k \times \frac{Do}{\sin\beta 1}$
(12)

Where , $^{\beta}$1- blade inlet angle =30°, when Attack angle α = 16°

$Thus,\quad S_b = 0.174 \times D_o$
(13)

7. Calculation of the radial rim width (α):

It is the difference between the outer radius [illegible] and inner radius (ri) of the turbine runner, and it [illegible] equal to the blade spacing and can be given as:

$\alpha = 0.174 \times D_o$
(14)

8. Calculation of the runner bl[illegible]de numb[illegible]

The number of the runner b[illegible] can be dete[illegible]ined as :

$n = \pi \times D_o/S_b$
([illegible]5)

9. Calculation of the w[illegible] jet thicknes[illegible]

It is also defined as nozzle [illegible] and can be [illegible]ated as ,

$t_j = \frac{A_j}{L}$

Where, Aj = Jet [illegible]

As, $Q = A_j \times V_j$

Therefore, $t_j = \frac{\frac{Q}{V_j}}{L}$ [illegible]

$Q/[C \times (\sqrt{2 \times g \times H_n}) \times L] = 0.233 \times Q/(L \times \sqrt{H_n})$
(16)

10. Calculation of runner length (L):

The runner length in (m) can be calculated as:
From reference [26]

$L \times D_o = 0.81 \times Q/\sqrt{H_n}$ (it is in metric units)
(17)

$L \times D_o = 210 \times Q/\sqrt{H_n}$ (it is in british units)
(18)

As we know, $D_o = 40 \times \sqrt{H_n}/N$

Putting above value in equation ------ (17)

$L = Q \times N/(50 \times H_n)$
(19)

By putting above value of 'L' into equation of Jet thickness (tj),

$t_j = \frac{A_j}{L}$

We obtain,

$tj = 11.7 \times \frac{\sqrt{H_n}}{N}$
(20)

From eq. of Do,-----[illegible]

$\frac{\sqrt{H_n}}{N} = \frac{D_o}{40}$, so pu[illegible]ng in e[illegible]on------- (20)

$tj = 11.7 \times \frac{D_o}{40}$

$tj = 0[illegible]9 \times D_o$ (m)
([illegible]21)

[illegible]. Calculation [illegible]f the distance betw[illegible]en water jet and [illegible] center of r[illegible]er shaft (y1)

y1 = 0[illegible] × Do (Imperical relation)
(22)

[illegible]2. Calcula[illegible] the [illegible]stance between water jet and [illegible]e inner periphery of ru[illegible]ner (y2) [26]

$y2 = 0.05 \times D_o$
(23)

[illegible]3. Calculation of inner diameter of the runner (Di)

[illegible]$_i = D_o - 2 \alpha$
(24)

14. Calculation of the radius blade curvature (r_c) [26]

$r_c = 0.163 \times D_o$
(25)

15. Calculation of the blade inlet and exit angles ($\beta_1$andβ_2) [26]

The blade inlet angle can be calculated as ,

$\tan\beta 1 = 2 \times \tan\alpha$

The blade exit angle β_2 =90^0 for perfect radial flow, but it must be equal to $\beta_1$at maximum efficiency.
(26)

V.APPROACH FOR DESIGNING:

Idea of designing integrated vanes/blade on rotor having some thickness, & shape is somewhat semicircular whose subtended angle is kept 120^0 , is came from the concept of banki water turbine. The difference between banki water turbine design & the turbine designed in this paper is that,bucket which having specific dimensions are mounted on the rotor by nuts and bolts while turbine discussed here having integrated vanes on the rotor this design may reduce the overall cost of the design & manufacture. The tangential water flow falling on the vanes causes the vanes to rotate & ultimately rotates the rotor, & to the keyed shaft. The shaft on which rotor is mounted is supported in stand by means of ball bearing in the stand.

For deciding geometry profile of the vane the referance is taken from paper 'Design & manufacture of micro zero head turbine for power genreation which was published in 2011'.

A thought behind designing semicircular vane is that when water strikes tangentially & go downwards to enter into next vane, maximum mass of water should enter cause the rotation of rotor to fulfill the purpose. The thickness of vane is decided from strength to thickness ratio.

By referring number of papers, the relationship of applied force of water can be given as-

$$F_i = \rho \times A \times V \times (V - u)$$

Where, F_i= Impact force (initial force)

ρ = water density.

V= Free stream/waterfall velocity.

A=Designed vane area.

u=tangential velocity of vane.

It is to be decided to kept 8 numbers of v es on the rotor whose outer diameter is 135mm, ce angle between two blades is maintained is 45^0, w falling some perticular heightis tangential to th backsurface of the vane, means initi he velocity of the blade is assumed to be zero, it means

So, $'F_i'$= initial force of water n be calcula as-

$F_i = \rho \times A \times V \times (V - 0)$ itially u=0

$F_i = \rho \times AV^2$

As wate nters into s vane, entered mass of water n su t to rotate so again its initial velocity u is consid as zero. But between two conse tive vanes kep 45^0, denoted . One importa ing is that flow of r on the bl de is kept tangential tate the rotor in direction only. So angle betwee waterflow & the back surface of a vane is considere α1 which 0 to 5^0.

$$Chord\ area = \frac{\theta}{360} \times Arclength$$

$$Chord\ area = \frac{120}{360} \times 32$$

Area=10.667mm²

i.e= Area=0.0010667m²

From above equation: $F_i = \rho \times AV^2$

Take value of $V_f = 1, 1.5, 2, 2.5, 3 m/sec$

1). $F_i = 1000 \times 0.0010667 \times (1)^2$

$F_i = 1.0667N$

2). $F_i = 1000 \times 0.0010667 \times (1.5)^2$

$F_i = 2.4N$

3). $F_i = 1000 \times 0.0010667 \times (2)^2$

$F_i = 4.2668N$

3). $F_i = 1000 \times 0.0010667 \times (2.5)^2$

$F_i = 6.6668N$

4). $F_i = 1000 \times 0.0010667 \times (3)^2$

$F_i = 9.6N$

From above explained designed procedure,

As circumferance of rotor is $2\pi R = 2 \times \pi \times 75 = 471.23mm$

And blade spacing is $S_b = .174 \times D_o$

$S_b = .174 \times 150$

$S_b = 26.1$

So, no of blades w be $\frac{23}{} = 18.05 \approx 18\,nos$.

But we are tak g minimu mbers of blades i.e. 08.

VI.CAL TIONS:

Approach to design this t e i starts from s ce availabi y accordingly maximu size is decided the turbine. this some parameters are assumed-

ρ_w ater de sity 1000kg/m³

g= g onal acceleratio 9.81m/s²

H_n=Net assumed 0.5 & 1m.

η_h=hydrau ficiency assumed 80%≈0.8

D_R=Rotor dia 35mm

D_p= Rotor pitch meter=150mm

V_f=Flow velocity=1m/s; 1.5m/s; and 2m/s.

As we know, $P = \rho_w \times g \times H_n \times \eta_h \times Q$

But, $Q = Area\ of\ turbine \times Flow\ velocity(V_f)$

flow velocity V_f=1m/s.

$$Q_1 = \frac{\pi}{4}(Dp^2) \times V_f$$

$$Q_1 = \frac{\pi}{4}(0.15^2) \times 1$$

$$Q_1 = 0.0176 m^3/s$$

II-For flow velocity V_f=1.5m/s

$$Q_2 = \frac{\pi}{4}(Dp^2) \times V_f$$

$$Q_2 = \frac{\pi}{4}(Dp^2) \times 1.5$$

$$Q_2 = 0.0265 m^3/s$$

III-For flow velocity V_f= 2m/s

$$Q_3 = \frac{\pi}{4}(Dp^2) \times V_f$$

$$Q_3 = \frac{\pi}{4}(Dp^2) \times 2$$

$$Q_3 = 0.0353 m^3/s$$

Case I- For Net head ***1 feet means 0.3m***.

$P_1 = \rho_w \times g \times H_n \times \eta_h \times Q_1$

P1=$1000 \times 9.81 \times 0.3 \times 0.8 \times 0.0176$

P1=41.43 watt

$P_2 = \rho_w \times g \times H_n \times \eta_h \times Q_2$

$P_2 = 1000 \times 9.81 \times 0.3 \times 0.8 \times 0.0265$

P2=62.39 watt

$$P_3 = \rho \times g \times H \times \eta_h \times Q_3$$
$$P_3 = 1000 \times 9.81 \times 0.3 \times 0.8 \times 0.0353$$
$$P_3 = 83.11 \text{ watt}$$

Case II- For Net head **0.5*m***.

$$P_1 = \rho \times g \times H \times \eta_h \times Q_1$$
$$P_1 = 1000 \times 9.81 \times 0.5 \times 0.8 \times 0.0176$$
$$P_1 = 69.06 \text{ watt}$$
$$P_2 = \rho \times g \times H \times \eta_h \times Q_2$$
$$P_2 = 1000 \times 9.81 \times 0.5 \times 0.8 \times 0.0265$$
$$P_2 = 103.986 \text{ watt}$$
$$P_3 = \rho \times g \times H \times \eta_h \times Q_3$$
$$P_3 = 1000 \times 9.81 \times 0.5 \times 0.8 \times 0.0353$$
$$P_3 = 138.51 \text{ watt}$$

VII.MATERIAL AND MANUFACTURING:

Selection of material: for the designed parts, as FDM RP technology is finalized to manufacture those parts so ABSM30-thermoplastic material is decided, to use this material having following properties: ABS M30 (acryolonitrile butadine sterene M30) is 25 to 70 percent stronger than standard ABS (acryolonitrile butadine sterene).

Greater tensile, impact, and flexural strength than standard Stratasys ABS.

Layer bonding is significantly stronger for a more durable part than standard Stratasys ABS.

Versatile Material: Good for form, fit and functional applications.

ABS M30 parts are stronger, smoother and have better feature details.

Tensile strength=36Mpa.

Tensile elongation [illegible]

Flexural stress=61Mpa

Izod impact=139J/m

Heat deflection=96^0

Unique properties= Variety of color options.

Density of material=(at 20^0C or 68^0F) >1 g/cm^3(>8.345lb/gal)

Young's modulus or modulus of elasticity= 1.4 -3.1(10^9 N/m^2 OR GPA)

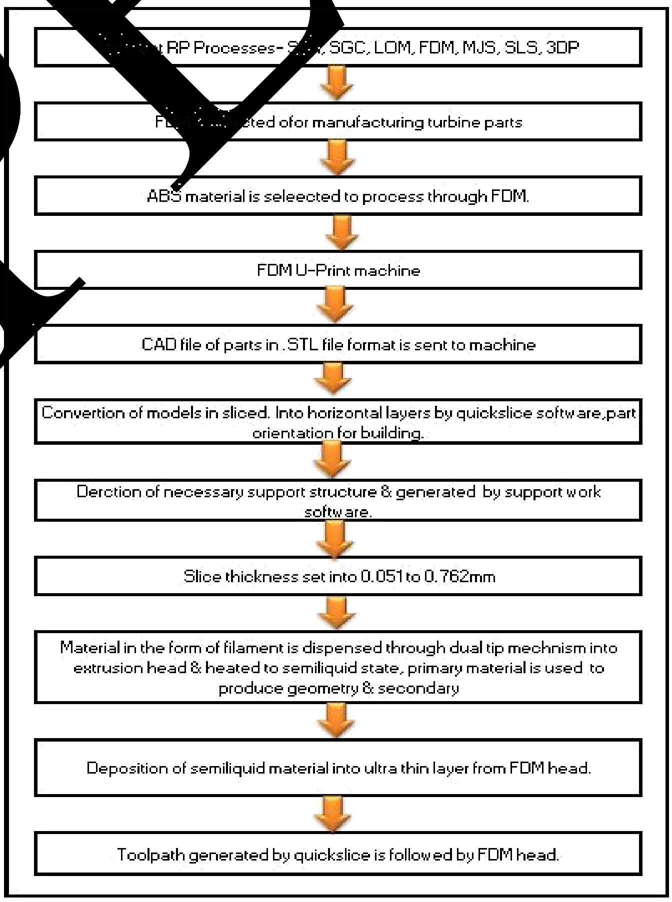
VIII.FORTUS SYSTEM OF FDM RP TECHNIQUE:

Fortus 3D production system offer unparalleded versatility and capability to turn CAD files into real parts, which are tough enough to be used as advanced conceptual models, functional prototyping, manufacturing tools and end use-parts. Variety of products can be produce just by loading different files and materials, which is not possible by traditional machining processes. Fortus system can produce a real end use thermoplastic parts directly form CAD files without using expensive tooling. Fortus 3D system is streamline process from design through manufacturing, reducing costs and eliminating traditional barriers along the way.

IX.SOFTWARE USED IN FDM:

Insight software: Insight software prepares 3D digital parts files (o/p as and .STL file) to be manufactured on a fortus system by automatically slicing and generating support structure and material extrusion path in a single push of button. If necessary user can override insights defaults to manually edit parameters that control the look, strength and precision of parts as well as the time throughput, expenses and efficiency of the FDM process.

Control center software: it is a software that communicates between the user workstations and fortus system, managing jobs and monitoring the production status of fortus system. It provides control to maximize efficiency, throughput and utilization while minimizing response time. This software is included with Insight software.



X. Flowchart for manufacturing of pico hydro turbine

XI.THEORY OF DESIGN:

Under this topic actual design of vertical flow waterwheel turbine is discussed. Uptill now work on designing and manufacturing of metallic water turbine for various purposes was done. So accordingly various head ranges turbines like high head, medium head, low head, micro head and pico head were designed, manufactured and was used for different applications. Aim of project is to design and to manufacture the turbine which can be efficiently used which having low design and manufacture cost also should be light in weight. By keeping this concept in mind, different parts of turbine are started to design. Initially primary conceptual drawing is completed. Sizes of parts are limited by space availability, and as type of hydro power is initially decided, which fixes range of power generation. After completing these basic things, next step was to it into 3D parts by using any 3D software. For 3D modeling of these parts Pro-e-wildfire software was used. Now for minimizing weight as well as cost advanced additive manufacturing technology was decided to use namely-Rapid prototyping. What is this RP technology and its different techniques it was explained in earlier chapter. By studying FDM RP technique is finalized. All 3D parts model are shown in appendix-I.

In a design rotor and shaft sizes are [illegible]re important, by theoretical calculations there is a [illegible]ange in power generation by changing the rotor [illegible] to what was those changes we taken three different si[illegible] rotor-135mm, 175mm, and 225mm. as a case study.

So accordingly RP machine enquiry w[illegible]ne, but cost of machine is few lacs which was no[illegible] so decided to write a proposal regarding [illegible]rchasing o[illegible]achine. As this process may take few [illegible] so it wa[illegible] decided to manufacture all these parts fr[illegible] suppli[illegible] to clear idea about q[illegible]ity and the[illegible]ulness of [illegible] product manufa[illegible] this RP te[illegible]ue. For this approached to "Design-[illegible] Pvt Ltd Comp[illegible]" based in pune (sup[illegible]ier of RP mach[illegible]). According [illegible]eed of techniq[illegible] 3D models of pa[illegible] converte[illegible] into .STP file, which [illegible] further used as [illegible]nput to RP-Fortus 360mc (FDM [illegible]hine). Important th[illegible] of this technique is that raw mate[illegible]sed for m[illegible]turing these parts was thermoplastic, [illegible]h makes parts light in weight, also life period is more [illegible] metallic part as they are free from corrosion, which [illegible]ces the life of parts. The peoples given estimation of manufacturing cost of those parts which is nearly 1.5lacs. Initially by including all cost parameters manufacturing cost goes very high. But after few years cost of product becomes very less. The parts coming through the machine are end user parts.

Before actually manufacturing these parts it was necessary to anlyze the very important part of turbine that is rotor, vanes integrated on outer periphery of rotor. So analysis of vane for checking stress strength at the given condition was checked in ansys14.5 software.

XII.TABULAR PRESENTATION OF ALL ANALYZED PARAMETERS FOR ALL THREE CASES:

Similarly, case three in which rotor size is 225mm and rotor pitch diameter is 250mm also vane size is different having thickness 4mm, height is 50mm.Accordingly results obtained are presented in tabular form as follows:-

Case	Hub dia	PCD	Area	Velocity	force	Pressure	Yield Strength	Von mises stress (Max)	Deformation
	mm	mm	m^2	m/s	N	Pa	Mpa	Pa	m
1	135	150	0.001	1	1	1000	40	904600	0.0001107
			0.001	1.5	2.25	2250	40	2035300	0.00024921
			0.001	2	4	4000	40	3618400	0.00044304
2	175	200	0.0021563	1.5	4.851675	2250	40	1018400	0.00014671
			0.0021563	2	8.6252	4000	40	1810400	0.00026082
			0.0021563	2.5	13.476875	6250	40	2828800	0.00040754
			0.0021563	3	19.4067	9000	40	4073500	0.00058685
3	225	250	0.0026953	1.5	6.064425	2250	40	1009100	0.00014545
			0.0026953	2	10.7812	4000	40	1793900	0.00025858
			0.0026953	2.5	16.845625	6250	40	2803000	0.00040404
			0.0026953	3	24.2577	9000	40	4036300	0.00058182

Table3: Tabular presentation of all analyzed parameters.

XIII. Advantages & Disadvantages of Microturbine-Advantages:

- Especially in mountainous areas where Grid Connection is expensive and unreliable micro hydro turbine is used.
- Micro turbines are few moving parts, compact systems, good efficiency.
- Micro turbines can operate continuously or On-demand and be either grid connected or stand alone. Not like the big hydro plants that use dams and create giant lakes behind the dams, micro-hydro plants only divert a small fraction of the stream and they don't need a water storage pool.
- In rare cases where the site is close to grid lines, part of the produced power can be sold back to the utility, and the grid serves as backup.
- The micro hydro plant requires low maintenance.
- Microhydro systems produce no pollution

DISADVANTAGES:

- As the power demand increases the size of the plant cannot be easily expandable.
- During the summer season there will be less flow and therefore less power output. Advanced planning and research will be needed to ensure adequate energy requirements.

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