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Design and Prototyping of Kaplan Turbine Runner Blade

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ABSTRACT

Presently the consumption of energy has been raising continuously with the growing rate of population. As for balancing the power consumption demand, renewable energy sources keep playing a vital place in covering the demand. The efficiency of a turbine is much affected by its runner wheel and this work aims to study the design of a Kaplan turbine runner wheel. First, a theoretical design was performed for determining the main characteristics where it showed an efficiency of 93%. Typically, theoretical equations are generalized and simplified and also they assumed constants of skilled data and hence a theoretical design will only be an approximate. This work aims at studying the Kaplan turbine mostly the kaplan runner wheel which is a reaction type turbine. And printing the prototype using rapid prototyping technique which is 3D Printing. Using FDM machine we need to print the prototype of kaplan turbine. So by this end of the project we let me know the how 3D printing works efficiently than other manufacturing methods. In this project we are using Solid works software for both design and simulation of a kaplan turbine runner blades. Inlet and outlet Velocities were founded out at an different angles by using CFD analysis method on solidworks software.

Keywords :— *Hydropower Kaplan Turbine; Power output; Blade angle Modelling; 3D Printing; Prototyping, CFD*

I. INTRODUCTION

1.1 Kaplan Turbine Working Principle:

The Kaplan turbine working principle is actually simple. These turbines design for a low water head so that a high outpour rate of water is permitted. Kaplan turbine works on the principle of the axial stream response. In an axial inflow turbine, the fluid moves by the impeller in a direction parallel to the impeller's axis of revolution.

1.2 Fused Deposition Modeling

In Fused Deposition Modeling (FDM) process a portable(x-y movement) snoot on to a substrate deposits thread of molten polymeric material. The frame material is warmed slightly above (like0.5C) its melting temperature so that it solidifies within a really short time (like0.1 s) after extrusion and cold-welds to the prior layer as shown in figure varied important factors need to be considered and are steady snoot and material extrusion rates, addition of support structures for overhanging features and speed of the snoot head, which affects the slice consistence. More recent FDM systems include two snoots, one for part material and other for support material. The support material is fairly of poor quality and can be broken smoothly once the complete part is deposited and is removed from substrate. In more recent FDM technology, water-solvable support structure material is used. Support structure can be deposited with minor density as compared to part density by supplying air gaps between two back-to-backroads.as shown in figure 1

3D printing is also known as cumulative manufacturing process. cumulative manufacturing refers to the manufacturing with the help of sub caste by sub caste system, by joining with each other. This technology changes the way of manufacturing in world now any product can be made with simply making its 3D modal or by viewing with the 3D scanner. We uses a CAD file to make objects on software further this file is uploaded to the 3D printer and it's made by printer. It can be used in where mass produce with high accurateness is needed. It also requires minor energy. Rapid prototyping has a wide range of employments in colorful fields of natural exercise engineering, medical industriousness, armed forces, construction, infrastructure, fashion, education, the computer industriousness and multiple others.

The main aim of this project is to design of kaplan turbine runner blade. To print the prototype of kaplan turbine runner blade using fast prototyping strategy called FDM The aim of this work is to review, assay and classify the study carried out on 3D printing between the periods 2014 and 2018. therefore, it's anticipated to understand in what way the studies are being carried out and what are the results achieved on the subject in recent times.

To achieve the better performance for kaplan turbine, design parameters of kaplan turbine similar as periphery of the runner, periphery of the mecca, number of blades, the blade angle, have to be considered for the runer. The rise in head is done only by the runer action with the help of the blades. The design and count of the blades will rise the pressure inside the covering, which in turn increases the head.

II. LITERATURE SURVEY

1. Tarun Singh Tanwar.

Fluid inflow conditions and parameters within a Radial Turbine with respects to each part of the turbine in contact with the working fluid and all working corridor of the Radial turbine set up that The maximum efficiency governance indicated by both approaches is nearly same. Reason for slight difference of efficiency reckoned by theoretically and CFD system can be because of mortal crimes and due to discretisation of disciplines and result of discriminational equations in computational styles[1].

2. Ketcheuzeu- NgakamJ.

Studied the Characterization of Hydrodynamics Parameters of a Kaplan Turbine by using Numerical analysis. set up that the static pressure is too high near the volute walls and inside the distributors [2].

3. Mohamed Adel.

Studied the Numerical disquisition of performance of kaplan turbine with draft tube. studied Kaplan turbine has a rotor with four blades mounted on a conical mecca. The blade angle of the rotor is malleable from 60° to 80°. A computational liquid unique law was employed(CFDRC, 2008) to demonstrate the temperamental two- stage sluice field around the sharp edges of the Kaplan turbine[3].

III. Design Procedure

3.1 Methodology

Design In the Solidworks software the model of physical prototype to be fabricated is designed. Solid model is automatically generated as the enclosed volume. thus prototyping the cross sections in direction must be limited arcs for generating a solid object.

Conversion to stl file After creating the model it's needed to convert the model into a file format compatible with the 3D printing. Small triangular sections are used to approach additional curving shell in stl file format.

Checking and preparing This stage involves or examining the design model stl train format followed by model medication of physical model fabrication in coming stage. Different softwares are available to check and repair the lines. Idea maker is one of the software. Its main ideal is to gain optimization and guiding of work inflow in 2d printing by enabling editing of stl train and data medication. The stl train is imported to the slicer software. After importing lines into software originally lines are viewed to check crimes which may lead to undesirable cracks, gaps, holes in physical model. also error are repaired using tools available for form in the software. After icing that stl lines free from crimes, data medication is carried out. data medication involves model slice data computation and determine other figure parameters the model is sliced into cross-sections. Thickness of each slice and other figure parameters similar as figure exposure, assortments of special movement are estimated using, analysis data

D printing In this stage fabrication of physical model is carried out in 3d printing machine. Once the 3D digital data is ready, publishing machine is loaded with needed material and machine is started for printing of the model. This stage is fully automated. Grounded on the size of the part and number of corridor to be fabricated, erecting process may extend up to hours. After completion of part printing, driver alert system gets actuated. Thereby driver can stop the machine and the part for post processing.

Post recycling post processing is the final stage of 3d printing process. In this stage prototype gained in printing is allowed to suffer different post processing operations similar as disemboweling, finishing, and post curing, grounded on the conditions. substantially post processing are carried out manually, thus driver has to deal precisely, without causing damage to the part. It may not be necessary to perform all post processing operations on beltbuilt.

3.2 Designing of Kaplan Turbine Runner Blade

1) Design Characteristics Calculations:

Runner blade is one of the most important factors in the Kaplan turbine. And to begin with the designing part of the same, parameters like power, inflow rate, and runner periphery first have to be determined. Depending upon the point named, the computations of these parameters are done in this section. The data on which the design of the runner is grounded is known as main characteristics. So for the computation of forces on the blade, the main characteristics are to attained.

2) Technical Highlights

- Canal head project
- Head range 5 to 21 m.
- Two turbo generators P= 9100kW rated capacity.

3) Power:

The equation for the output power is as follow:

$$P = \rho Q V_{w1} u_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

Where,

ρ = Density of Water [Kg/m^3] = 1000 Kg/m^3
Q = Discharge [m^3/s]

u_1 = Velocity of the blade at inlet [m/sec]

V_{w1} = Tangential Velocity at inlet [m/sec]

$$P = \rho Q V_{w1} u_1$$

Where V_{w1} *and* u_1 are unknown that can be find by using following formulas

4) Speed Ratio:

$$k_u = \frac{u_1}{\sqrt{2gH}}$$

$$u_1 = k_u \times \sqrt{2gH} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

The value of the Speed ratio for kaplan turbine runner varies from 1.5 to 2.2.We are assumed that $k_u = 2.09$ and subtituted in equation[2].

$$u_1 = 2.09 \times \sqrt{2 \times 9.81 \times 5.6}$$

$$u_1 = 21.95\ m/sec$$

5) Flow Ratio:

Velocity of flow is unknown, which can be calculated from the equation given below

$$flow\ rate\ k_f = \frac{V_{f1}}{\sqrt{2gH}}$$

Where k_f = Flow ratio

$$V_{f1} = k_f \times \sqrt{2gH} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3]$$

Usual range of k_f for a kaplan turbine is 0.5 to 0.8. We are assumed that k_f = 0.68 and subtituted into above equation[3].

$$V_{f1} = 0.68 \times \sqrt{2 \times 9.82 \times 5.6}$$

$$V_{f1} = 7.12\ m/sec$$

We assume $\alpha = 45^0$

$$tan\alpha = \frac{V_{f1}}{V_{w1}}$$

$$tan45^0 = \frac{7.12}{V_{w1}}$$

$$V_{w1} = \frac{7.12}{\tan 45^0}$$

$$V_{w1} = 7.12\ m/sec$$

6) Discharge (Q):

All the above values are substituted in the equation [1]

$$9100 = 1000 \times Q \times 7.12 \times 21.95$$

$$Q = \frac{9100}{1000 \times 7.12 \times 21.95}$$

$$Q = \frac{9100}{156284}$$

$$Q = 0 \cdot 059\ m^3/sec$$

7) Diameter of the Runner and Hub:

To calculate the diameter of the runner Do, following equation is used

$$Q = \frac{\pi}{4}\left[{D_o}^2 - {D_b}^2\right] \times V_{f1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots[4]$$

Where, V_{f1} = Velocity of Flow [m/s]

D_o = Diameter of Runner [m]

D_b = Diameter of Hub [m]

A relation between runner diameter and hub diameter

$$D_b = \frac{D_o}{3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[5]$$

That is written by D_o = 0.33 D_b .We know all the values substitute in equation[4]

We know that $Q = \frac{\pi}{4}\left[{D_o}^2 - {D_b}^2\right] \times V_{f1}$

All the values are substituted in the equation[4]

$$= \frac{\pi}{4}[(3D_b)^2 - {D_b}^2] \times 7.12$$

$$= \frac{\pi}{4}[(D_b)^2[3^2 - 1^2] \times 7.12]$$

$$= \frac{\pi}{4}[(D_b)^2[9 - 1] \times 7.12]$$

$$= \frac{\pi}{4}[(D_b)^2 \times 8 \times 7.12]$$

$${D_b}^2 = \frac{0.059}{\frac{\pi}{4} \times 8 \times 7.12}$$

$${D_b}^2 = 1.31 \times 10^{-3}$$

$$D_b = \sqrt{1.31 \times 10^{-3}}$$

$$D_b = 0.03\ m$$

Diameter of the Hub $D_b = 0.05\ m$ by substituting this value into equation [5]. we get diameter of the runner.

$$D_o = 3 \times D_b$$

$$D_o = 3 \times 0.033$$

$$D_o = 0.09 \text{ m}$$

Therefore diameter of the hub $D_b = 0.03\ m$

Diameter of the Runner $D_o =$ 0.09 m

8) Overall efficiency :

overall efficiency can calculated by using following formula

$$\eta_o = \frac{S.P}{W.P}$$

$$\eta_o = \frac{9100}{\frac{\rho g Q H}{1000}}$$

$$\eta_o = \frac{9100}{\frac{1000 \times 9.81 \times 0.059 \times 5.6}{1000}}$$

$$\eta_o = 0.73$$

$$\eta_o = 73.33\%$$

9) Hydraulic Efficiency:

$$\eta_h = \frac{V_{w1} \times u_1}{gH}$$

$$\eta_h = \frac{7.12 \times 21.95}{9.81 \times 5.6}$$

$$\eta_h = \frac{15.36}{54.93}$$

$$\eta_h = 0.82$$

$$\eta_h = 82\ \%$$

10) Speed of the Runner:

We know that Velocity of the blade at inlet is 21.95 m/sec and diameter of the runner that will be substituted in the following equation. We get runner speed.

$$u_1 = \frac{\pi D_o N}{60}$$

$$21.95 = \frac{\pi \times 0.09 \times N}{60}$$

$$N = \frac{21.95 \times 60}{\pi \times 0.09}$$

$$N = 4158\ rpm$$

11) Specific Speed :

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

$$N_s = \frac{3158 \times \sqrt{9100}}{5.8^{5/4}}$$

$$N_s = \frac{3158 \times \sqrt{9100}}{5.8^{5/4}}$$

$$N_s = \frac{3158 \times 95.39}{9.001}$$

$$N_s = 997\ rpm$$

12) Process of completing the sketches

- Selecting any one of the plane from the available planes in the sketch menu present
- opting any one of the plane from the available planes in the sketch menu present
- FDM working procedure as shown in Figure 1.
- Figure 2 shows the creation of plane 1.
- By using sketch objects shape like as lines, circles, cube etc the 2D model is created.
- Now make an another profile with mean of former profile.
- Some what twisted with some twist angle while designing a mean profile. As shown in figure 3. also make the tip.
- After that extrude all the three profiles by using loft command. First we've created a plane for each profile section of the loft. The plane don't need to be like.
- Sketch the section profiles on the planes.
- Click Launched face(shells toolbar) or Insert> Features> garret.
- Set the Property Manager options.

- Click OK As shown in figure 4.
- Select a plane on the 3D model and draw a circle of needed dimension using sketch realities figure. After creating circle on the plane.
- Select the circle also using extrude command to add the material. As shown in figure 5.
- Produce a new 2D sketch. produce all solid sketch figure on one side of the axis.
- Choose Revolve Boss/ Base from the features menu.
- Pick the axis you wish to use for the revolve.
- Specify direction and angle.
- Accept the point. As shown in figure 6.
- Click Insert> face> Extrude.
- Select a face
- To banish from a 3D face, elect a 3D face. Select an axis to extrude.
- The final design of master is show in figure 7.

13) Slicing Using IdeaMaker Software

- Stoner interface is shown in figure8. First we need to import the model which we've designed using solidworks into idea maker.
- By click on import model. Shows figure 8.
- Also we've to click on launch slicing.
- Elect main template for printing.
- Click on slice. show figure 9.
- For knowing the how important time took for publishing the element click on exercise.
- In print exercise that automatically shows estimated time, estimated quantum of material, and estimated cost as well. Shows figure 10.
- It'll also shows different colours for support and factual materials.
- We can elect which colour we want. Shows figure 11.
- Originally the printing of the element starts with making a base or support on the bed of printer. As shown in the below figure, the hands or moving jaws of the printer moves grounded on the x, y, z axis and a base is published before going to print original component. Shows figure 12.
- Above shown figure is the 3D printing machine that we've used throughout the printing work. It's a Fused Depositioning system type of publishing machine which uses hair line which is originally in solid state and made into molten state by the increased temperature. These molten hair is made to follow the pattern as the design presents, and with the help of portable jaws the hair prints the element sub caste- by- subcaste with respect to co-ordinates. figure 13.

14) CFD analysis using SolidWorks Software

- After opting the faces click on input data in which we're giving fluid sub domins.
- Click on boundary conditions> opt the inlet speed and environmental presure
- Click on mesh to induce themesh. shows figure 14.
- After generation of mesh follow the ensuing path Flow simulation> Projects> Flow trajectories 1> Run.
- We'll get the results automatically and we can see the stream variation on different colours.

- Figure 21 shows speed of stream at an angle at completely opened.
- By adjusting the blade angles to zero degrees we can get the maximum speed.
- As water strikes the blade at zero degrees speed increases.

15) Results And Discussions

- Max velocity accours at an angle of 1800degrees.as shows in figure 15.
- When the angle of the blade increases speed gets falls.

16) Scope of Further Work

In coming probation, CFD study can be conducted on the hydro-mechanical elements of water turbines for advancement to gain optimum results. Likewise, coming exploration work in the exploration field of hydro- power development in the developing countries;

- Study on the use of compound material as backup to the conventionally used materials on blades for the cost effectiveness and better and better performance.
- To research for advancement in the turbine efficiencies depending on the blade tip allowance criteria using CFD systems.
- To research work on the turbine balancing systems using ultimate computational systems.
- Research work in the area of hydraulic structures need further attention. Use of CFD can lead to bettered and optimum design of hydraulic structures like gates, stop logs, trash racks etc.

IV. Figures and Tables

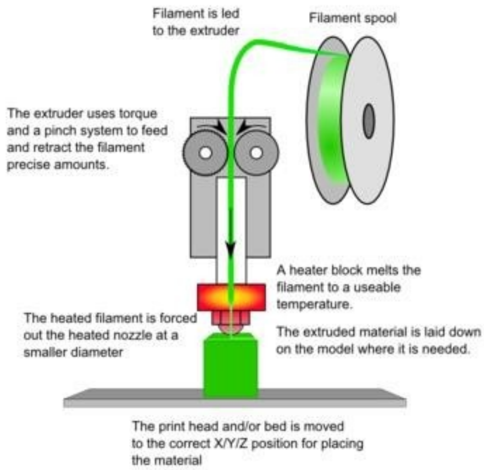

Figure 1 : Fused deposition modelling process[1]

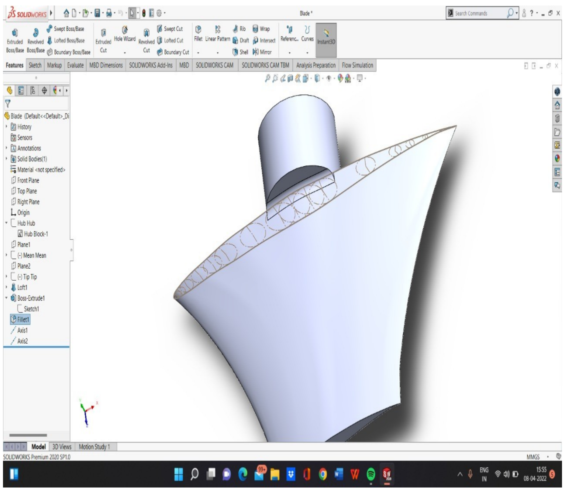

Figure 2: Creation of plane 1

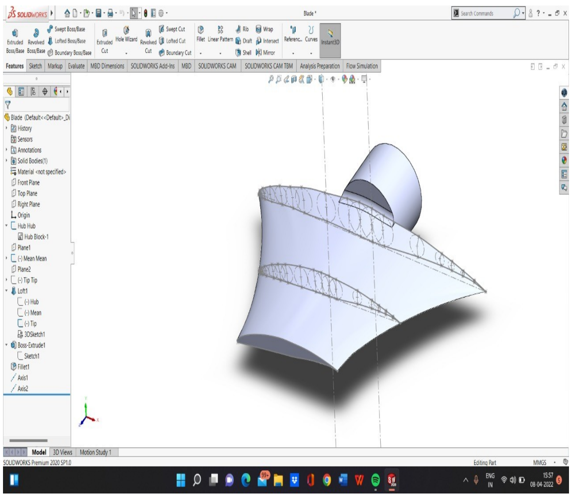

Figure 4: Creation of plane 2

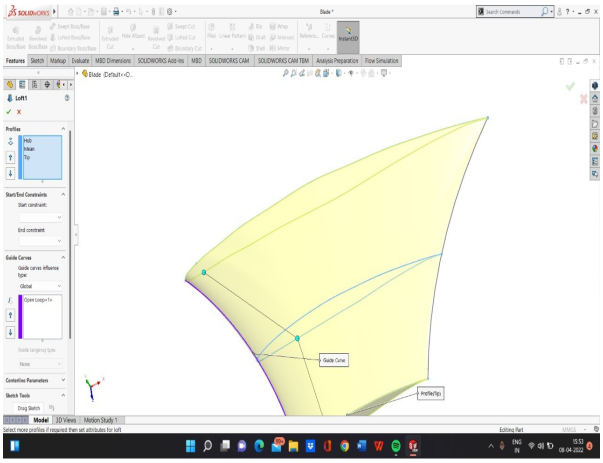

Figure 5: Creation of Loft

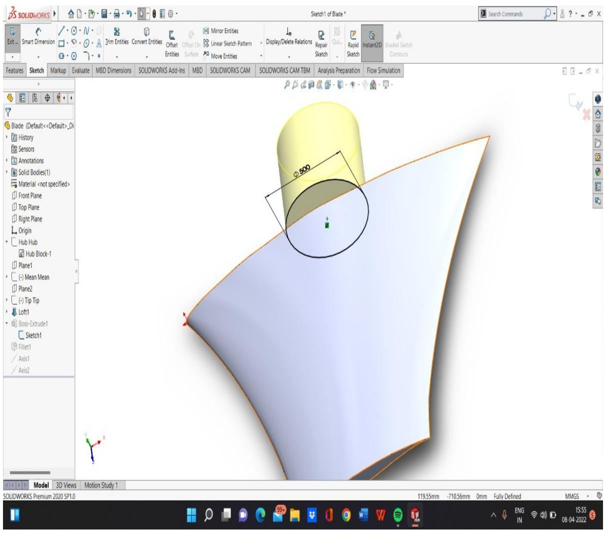

Figure 6: Design of Hub Block

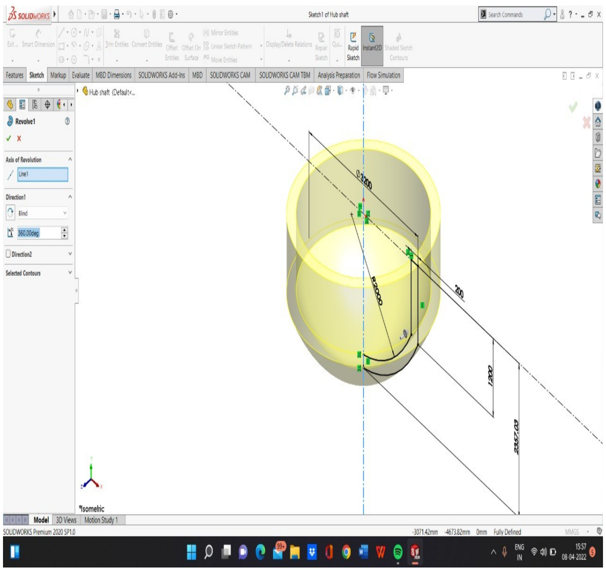

Figure 8: Design of Boss

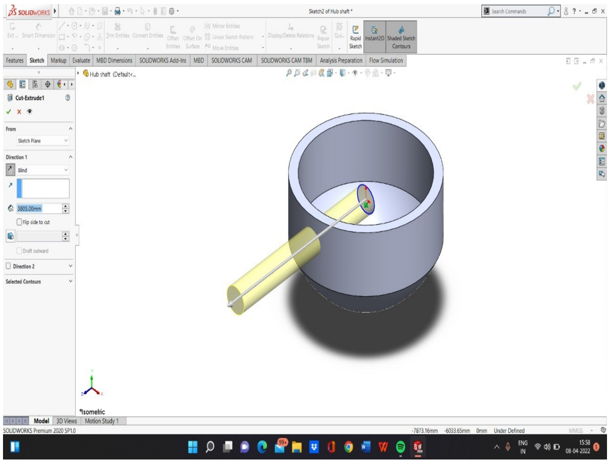

Figure 9: Design of Hole on Boss

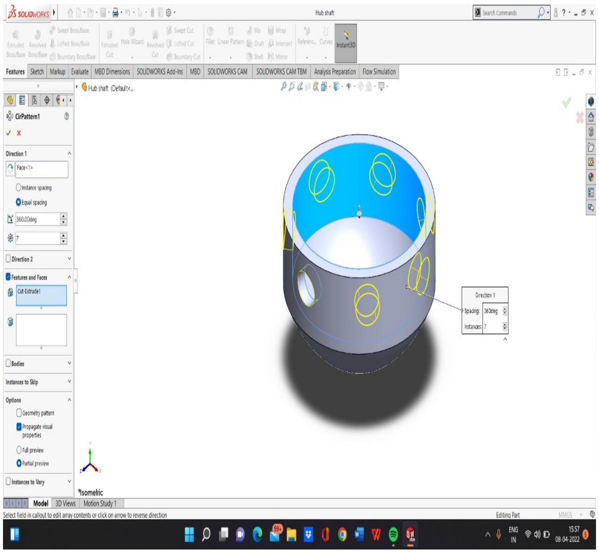

Figure 10: Cir Pattern For Making Equal Number of Holes

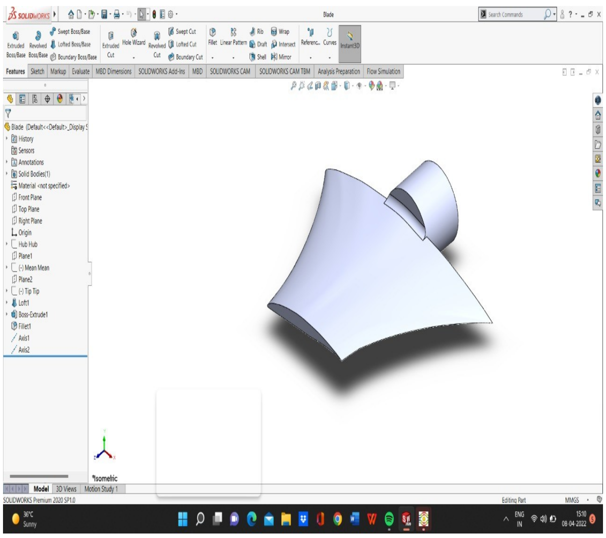

Figure 14: Final design of blade

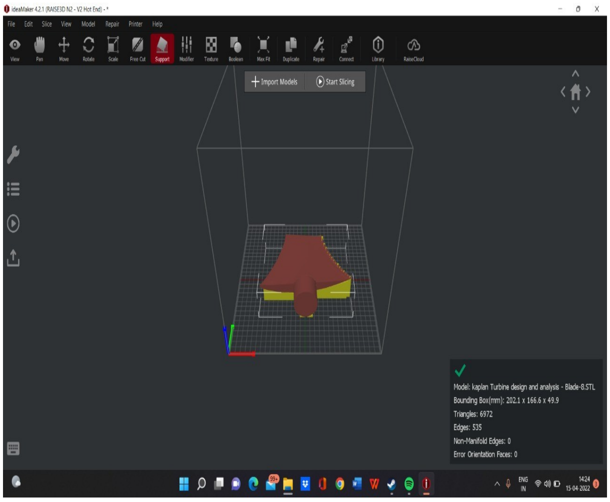

Figure 15: Importing the Model

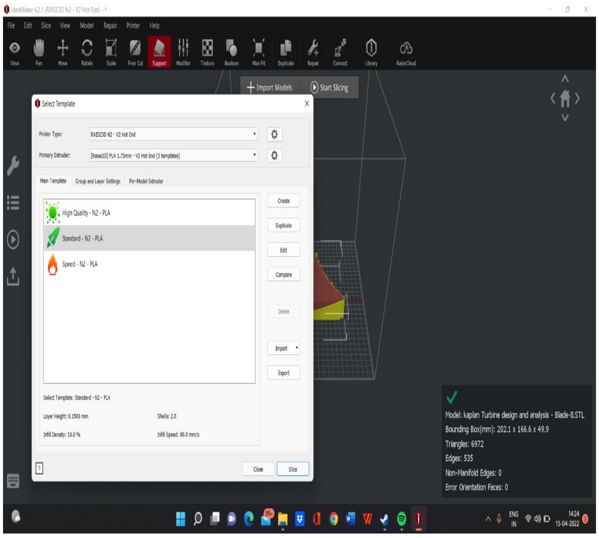

Figure 16: Selection of Main Template

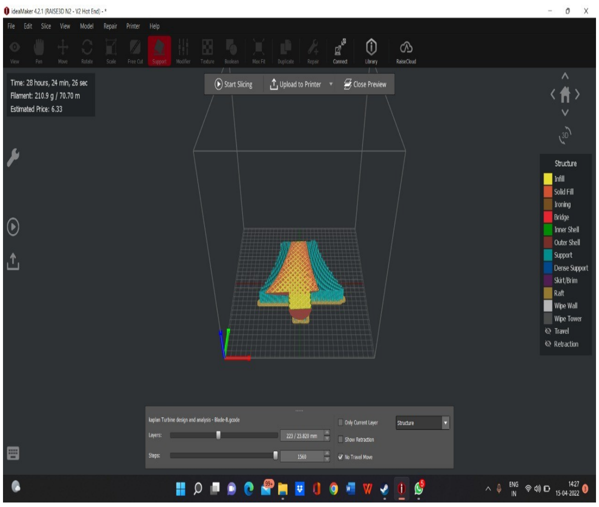

Figure 17: Preview For Number of Layers And Steps

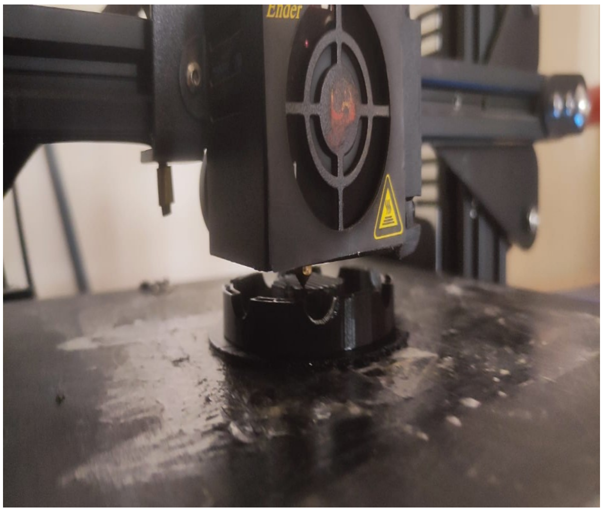

Figure 18: Start Printing the Actual Prototype

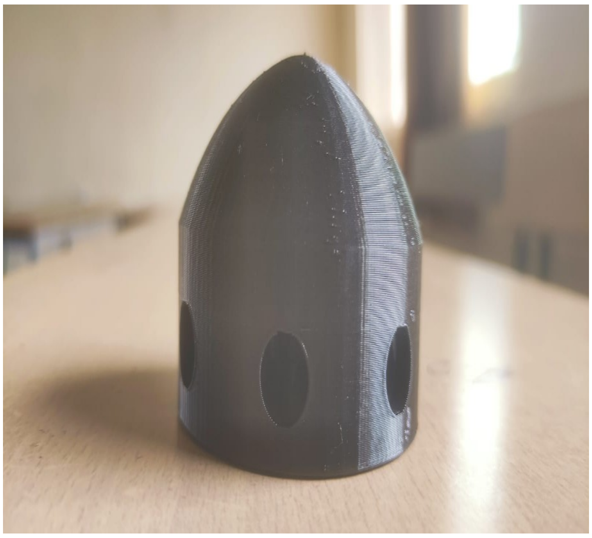

Figure 19: After Completion of Prototyping of Boss

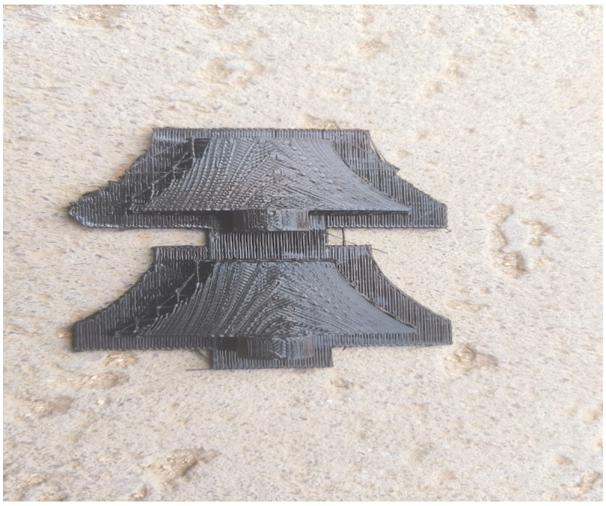

Figure 20: After Completion of Prototyping of Blades

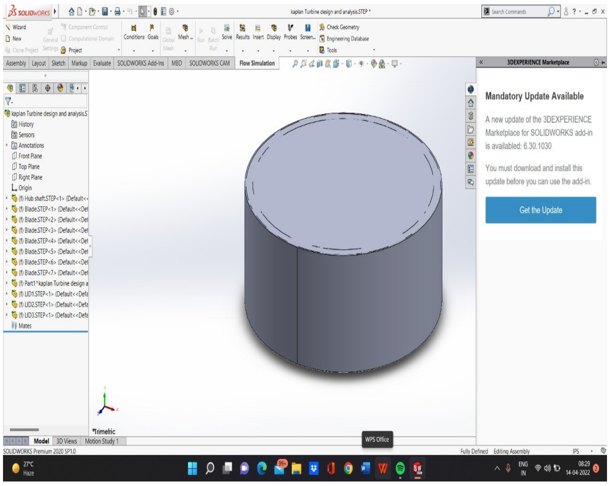

Figure: 21 Shell Creation

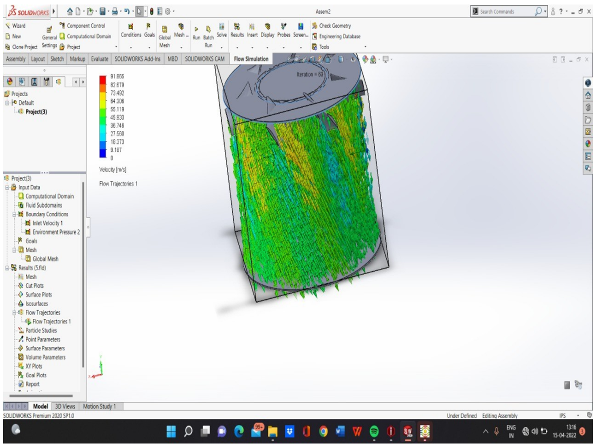

Figure 22: Velocity at blade angle at Fully opened

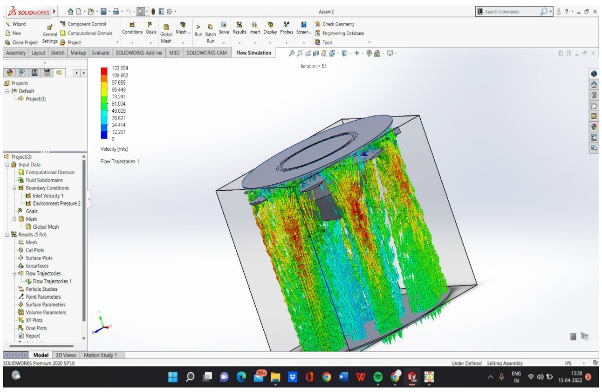

Figure 23: Velocity At Blade Angle at Fully Closed

Table 1: Result of Velocities At Various Angles

Velocity	Fully opened	Fully Closed
Maximum	91.86	122.069
Minimum	0	0

Table 2: Result Data of Main Characteristics

Parameter	Symbol	Value	Unit
Power	P	9100	kW
Gross Head	H	5.8	m
Overall efficiency	η_o	0.73	-
Hydraulic Efficiency	ηh	0.82	-
Flow Rate	Q	0.059	m3/s
Net Head	Hn	5.6	m
Specific Speed	Ns	997	rpm
Runner Speed	N	4158	rpm
Flow Speed	k_f	0.68	-
Velocity of Flow	Vf1	7.12	m/s
Runner Diameter	Do	0.09	m
Hub Diameter	Db	0.03	m

V. CONCLUSION

In this project, the kaplan turbine was designed using thearetical computations. furthermore the kaplan turbine runner was printed by using rapid prototyping methodology called fused deposition modelling. And done simulation using CFD analysis using solidworks software. The design and prototyping of Kaplan turbine runner blade using computational fluid dynamics tools. 3DCAD model of the runner blade is generated from the article measures. Complex geometrical profile of the blade is developed using SolidWorks for the purpose to dissect using CFD. overall turbine efficiency of 73%. Results of the exploration study carried out on the CAD model of original blade.

We had done the article arithmetics so that by using main characteristic arithmetic's we had design a Kaplan turbine runner blade in SolidWorks software. And simulations would performed on solidworks software.

VI. ACKNOWLEDGEMENTS

We would like to express our sincere thanks and gratitude to our Principal, Dr. S. Sreenatha Reddy and Head of the Department Dr. B. Vijaya Kumar, Department of Mechanical Engineering, Guru Nanak Institute of Technology for having guided us in developing the requisite capabilities for taking up this project. We specially thank our internal guide Mr. A. Vijay Kumar Assistant Professor, Department of Mechanical Engineering for his constant guidance in every stage of the project. (12)

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