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Design and Prototyping of Pelton Wheel

Mr. K Vinay Kumar¹, M. Vamshidhar Reddy², Mameli Srineeth³, Malvica Ramesh Sangeetham⁴,

Assistant Professor, Department of Mechanical Engineering, Guru Nanak Institute of Technology, Ibrahimpatnam,

R.R. Dist, India

Department of Mechanical Engineering, Guru Nanak Institute of Technology, Ibrahimpatnam, R.R. Dist, India

ABSTRACT: The Pelton turbine can be used as a two-phase expander. The characterization of the Pelton turbine as two-phase expander consists in analysing the power loss sources to evaluate the machine performance. The design of Pelton turbines has always been more difficult than that of reaction turbines, and their performances lower. A Pelton turbine bucket is the individual component which makes up the turbine section of a Pelton turbine. The buckets are responsible for extracting energy from the high-pressure water produced by the nozzle jet, the Pelton bucket are very often the limiting component of Pelton turbines. To survive in this difficult environment, Pelton Wheel buckets often use exotic material.

In this project, Pelton turbine is designed and modelled in modelling software called SOLIDWORKS. We know that the efficiency is directly related to material performance, making the material selection is the primary importance in this project. Materials considered for Pelton Wheel are Alloy Steel, Aluminium Alloy and Stainless Steel. Optimization is done by using these material by performing Computational Fluid Dynamics on the designs.

The objective of this project is to perform coupled filed analysis of Pelton wheel bucket for various material on the Pelton wheel for finding out the efficiency, high stress handing factors, Displacement and Equivalent Strain. There after the component should be print using 3D Pinter. The change in material and pressure will lead to changes in the values of Displacements, Stress and Strain leading to resonance which will cause the failure of the equipment. Hence the CFD analysis is to be done. The proposed material is subjected with a certain velocity of water striking the buckets. The CFD analysis gives the distribution of Pressure, density, velocity and stress. After analysing the component, the Solid Works design file should convert into STL file format. Then after import the STL file to 3D Printing software for slicing into layer-by-layer and Prototyping of Pelton wheel is done using Ender FDM 3D Printing machine.

KEY WORDS:SolidWorks, CFD analysis, 3D Printing.

I.INTRODUCTION

1.1 Introduction to 3DPrinting

3DPrintingtechnology,alsoknownasAdditiveManufacturing(AM),referstoprocessesused to generate a 3D object in which layers of material. The creation of a 3D printed object is achieved usingadditiveprocesses.Inanadditiveprocessanobjectiscreatedbylayingdownsuccessive layers of material until the object are successively formed under acomputer- controlled program to create a physical object is created. Each of these layers can be seen as a thinly sliced cross-section of theobject. [6]



Figure 1.1 Step by Step process of 3D Printing. [5]

1.2 Fused Deposition Modelling (FDM)

As explained earlier, the FDM process was the second type of additive manufacturing created and is one of the most used processes because of its low cost. In this process, thermoplastic filaments are heated in the extruder and deposited on the construction platform by means of the extrusion nozzle. The construction platform has a lower temperature than the deposited thermoplastic, causing it to solidify rapidly. The platform moves down, and the nozzle of the extruder deposits the second layer of material. This process is repeated until the object is created.

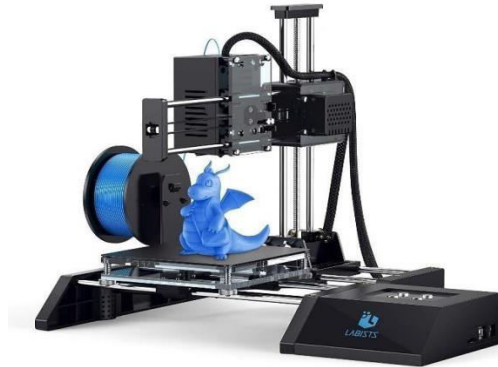


Figure 1.2 Fused Deposition Modelling (FDM) Printer [4]

1.3 Introduction to Pelton wheel

The turbines, a subgroup of rotor dynamic machines are used to produce power utilizing converting hydraulic energy into mechanical energy. They are of different types according to their specification. Turbines can be subdivided into two groups, impulse and reaction turbines. Moreover due to working fluid used, turbines can be named as steam turbines, gas turbines, wind turbines, and water turbines. Pelton wheel, named after an eminent engineer, is an impulse turbine wherein the flow is tangential to the runner and the available energy at the entrance is completely kinetic energy. Pelton wheel is preferred at a very high head and low discharges with low specific speeds. The pressure available at the inlet and the outlet is atmospheric. This type of turbine was developed and patented by L.A. Pelton in 1889 and all the types of turbines are called by his name to honour him. [7]

1.4 Working principle of Pelton wheel turbine

The working principle is water is coming from the storage reservoir through a penstock to the Inlet of the nozzle which is the inlet of the turbine so the hydraulic energy of the water is mainly converted into kinetic energy. The water releases in the form of a jet from the nozzle and strikes on the vanes for a very small-time duration.

Since a very high force is exerted on the vanes by the jet of water for a very small-time duration so these turbines are known as Impulse turbines. Bucket changes the direction of run/flow of water jet and momentum transfer takes place.

All events happen in open air i.e., at atmospheric pressure. The nozzle is used to convert the head available with water into a dynamic head and the water comes out from the nozzle in the form of a jet. As the jet strikes over the runner vane, it will apply a large magnitude force for a small amount of time over the runner called Pelton force the Pelton force will rotate the runner.

II. LITERATURE REVIEW

1. "INVESTIGATION OF MANUFACTURING OF A PELTON TURBINE RUNNER OF COMPOSITE MATERIAL ON A 3D PRINTER", A. Murad GÜLLÜOĞLU, Oğuzhan BENDEŞ, Buğra YILMAZ, Adem YILDIZ.

Various approaches are now employed in the industrial industry. One of these is the 3D printing production technology, often known as additive manufacturing. In this work, a Pelton turbine bucket was printed on a 3D printer using a composite material (carbon + thermoplastic) and evaluated. Analytically, the TEMSAN special Pelton turbine bucket has a unique form structure. When compared to steel fabrication, the turbine runner was created faster and more cost-effectively using additive manufacturing. The tests were conducted at the TEMSAN Hydraulic Test Laboratory at pressures ranging from 5-7.5 bar and flow rates of 26 l/s and 46 l/s. 1775 N was discovered to be the maximum breaking strength value. [1]

2. “DESIGN OF A PELTON WHEEL TURBINE FOR A MICRO HYDRO POWER PLANT”, Manjunatha N, Kuldeepak Kumar, Dr. Thammaiah Gowda.

The energy obtained by water in the Pelton wheel is turned into kinetic energy by creating a nozzle at the end of the penstock. The Pelton wheel was run at a low flow rate and a high head. In order to execute Pelton in the creation of a micro-hydropower plant under varied operating circumstances, turbine parameters must be included in the design method. All of the design parameters were computed in this study. Turbine power, runner diameter, runner speed, bucket dimensions, number of buckets, and turbine specific speed were among the characteristics considered. [2]

3. “DESIGN, MODELLING AND ANALYSIS OF PELTON WHEEL TURBINE BLADE”, Prof. V.M. Prajapati, Prof. R.H. Patel, Prof. K.H. Thakkar.

This paper primarily focuses on the physical attributes of a Pelton Wheel Turbine and how we can improve its efficiency. Due to its simple structure and ease of manufacture, the Pelton turbine was used in the building of a micro-hydroelectric power plant with a high head and low water flow. The turbine characteristics must be considered in the design method to achieve a Pelton hydraulic turbine with optimal efficiency under varied operating situations. All design parameters were estimated as efficiently as possible using MATLAB SOFTWARE. Turbine power, torque, runner diameter, runner length, runner speed, bucket dimensions, number of buckets, nozzle dimension, and turbine specific speed were among the characteristics considered. [3]

III. MODELING

3.1 Design of Pelton Wheel

The design of Pelton wheel is simple, where a large circular disk is mounted on some sort of rotating shaft known as a rotor. Buckets are mounted on this circular disk are in cup shaped blades evenly spaced around the entire wheel. The buckets are arranged in pairs around the wheel. Then nozzles are arranged to introduce the water to the turbine. Jets of water emerge from these nozzles, tangential to the wheel of the turbine. This causes the turbine to spin as a result of the impact of the water jets on the buckets.

3.2 Drafting using SolidWorks

After deciding the best case design we moved to the software for drawing the Pelton wheel which consist of runner and buckets. By using the SolidWorks software we had done the design with all the required parameters of Pelton wheel.

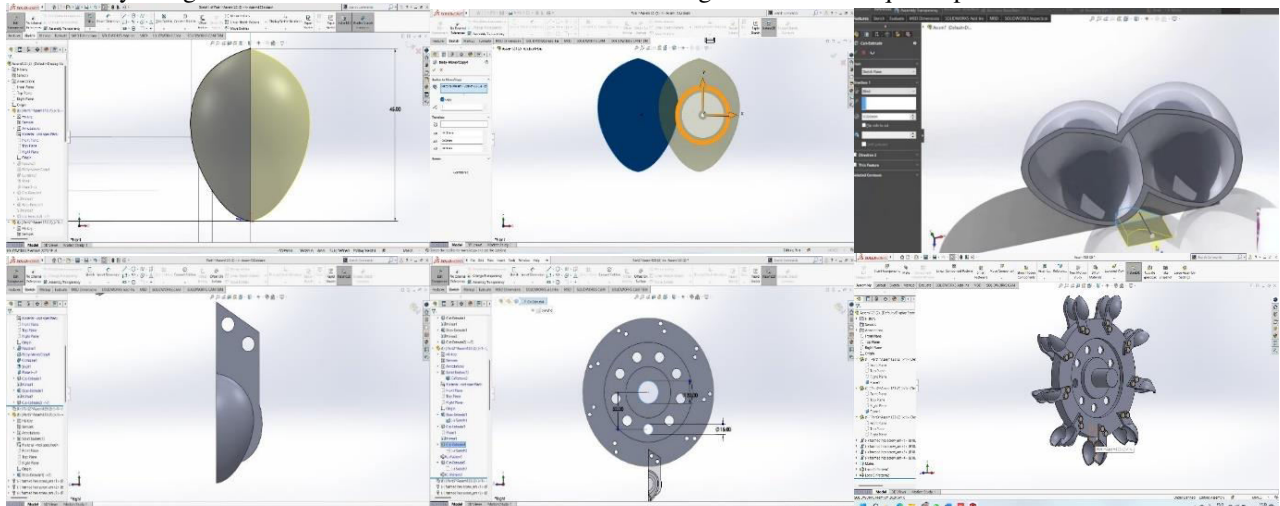


Figure 3.2 Different Stages of Pelton wheel Design using Solid Works

IV. ANALYSIS

4.1 CFD Analysis Using SolidWorks

Analysing the 3D model of Pelton wheel using SolidWorks software, considering the flow simulation of Pelton wheel in a closed boundary condition which gives the result on pressure and velocity of water striking the buckets.

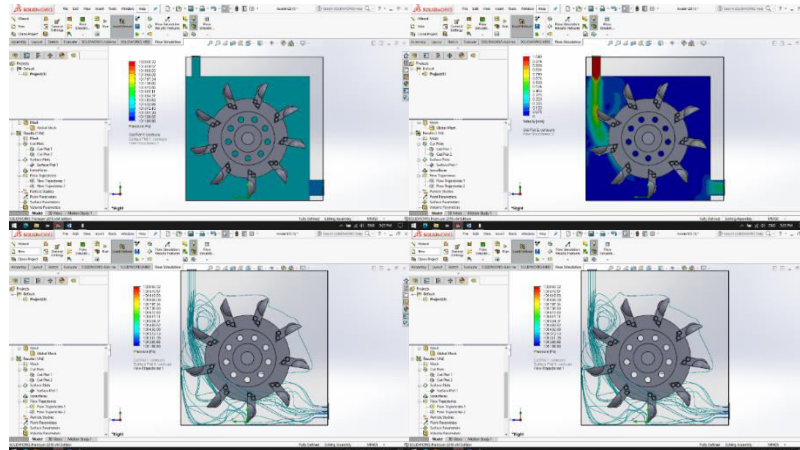


Figure 4.1 Analysing Pressure and Velocity of water striking the Buckets.

4.2 Alloy Steel

The Equivalent stresses of Static Stress, Displacement and Static strain are shown below. When subjected the considered pressure (101325 N/m^2) and it is observed that the Static stress, Displacement and Static Strain produced in Pelton Wheel under the range starting from $7.395 \text{e} + 003 \text{ N/m}^2$ to $3.644 \text{e} + 007 \text{ N/m}^2$ was found at Nodes 1031 and 906, $0.000 \text{e} + 000 \text{ mm}$ to $2.230 \text{e} + 002 \text{ mm}$ were found at Nodes 885 and 1765, $3.413 \text{e} - 008$ to $1.276 \text{e} - 004$ was found at Elements 2612 and 4037.

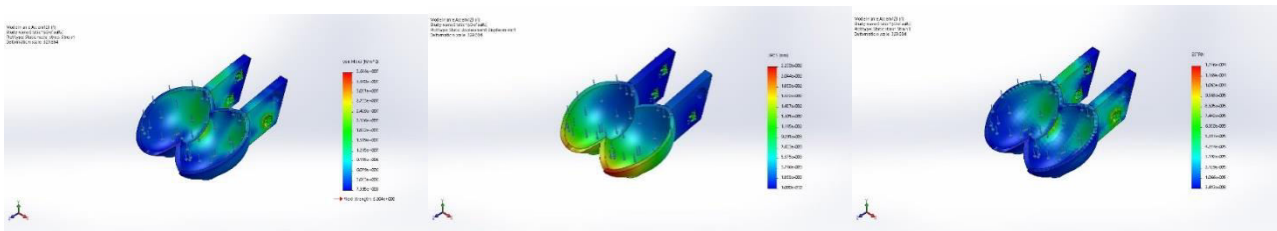


Figure 4.2 Static Stress, Displacement and Static Strain in Alloy Steel

4.3 Aluminium Alloy

The Equivalent stresses of Static Stress, Displacement and Static strain are shown below. When subjected the considered pressure (101325 N/m^2) and it is observed that the Static stress, Displacement and Static Strain produced in Pelton Wheel under the range starting from $2.311 \text{e} + 03 \text{ N/m}^2$ to $1.217 \text{e} + 08 \text{ N/m}^2$ was found at Nodes 3288 and 3209, $0.000 \text{e} + 000 \text{ mm}$ and a maximum of $6.254 \text{e} - 02 \text{ mm}$ were found at Nodes 1565 and 2090, $8.292 \text{e} - 08$ to $7.807 \text{e} - 04$ was found at Elements 19397 and 14973.

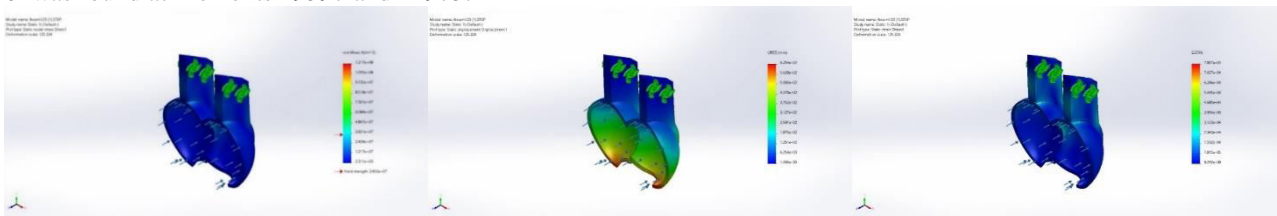


Figure 4.3 Static Stress, Displacement and Static Strain in Aluminum Alloy

4.4 Stainless Steel

The Equivalent stresses of Static Stress, Displacement and Static strain are shown below. When subjected the considered pressure (101325 N/m^2) and it is observed that the Static stress, Displacement and Static Strain produced in Pelton Wheel under the range starting from $2.241 \text{e} + 03 \text{ N/m}^2$ to $1.093 \text{e} + 08 \text{ N/m}^2$ was found at Nodes 2964 and 28427, $0.000 \text{e} + 000 \text{ mm}$ and a maximum of $2.262 \text{e} - 02 \text{ mm}$ were found at Nodes 1415 and 1877, $2.781 \text{e} - 08$ to $3.644 \text{e} - 04$ was found at Elements 13371 and 6664

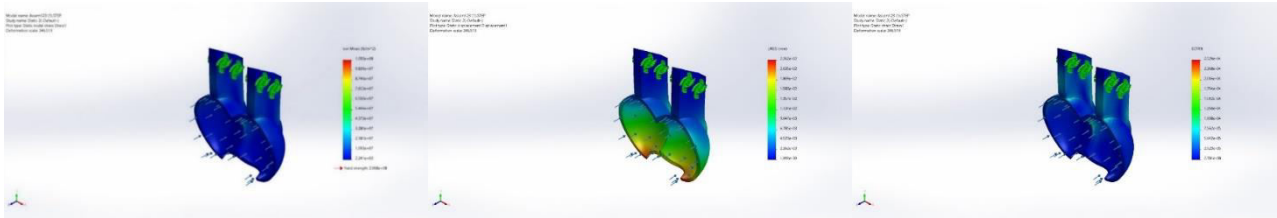


Figure 4.4 Static Stress, Displacement and Static Strain in Stainless Steel

4.5 Slicing the SolidWorks model into layer-by-layer process

Slicing the 3D cad model by using the Creality slicer software and insert file, set the position of the Pelton wheel in horizontal/ vertical direction to print easily in less time. Then convert this into G-codes and M-codes to print the component using FDM Ender 3D printer.

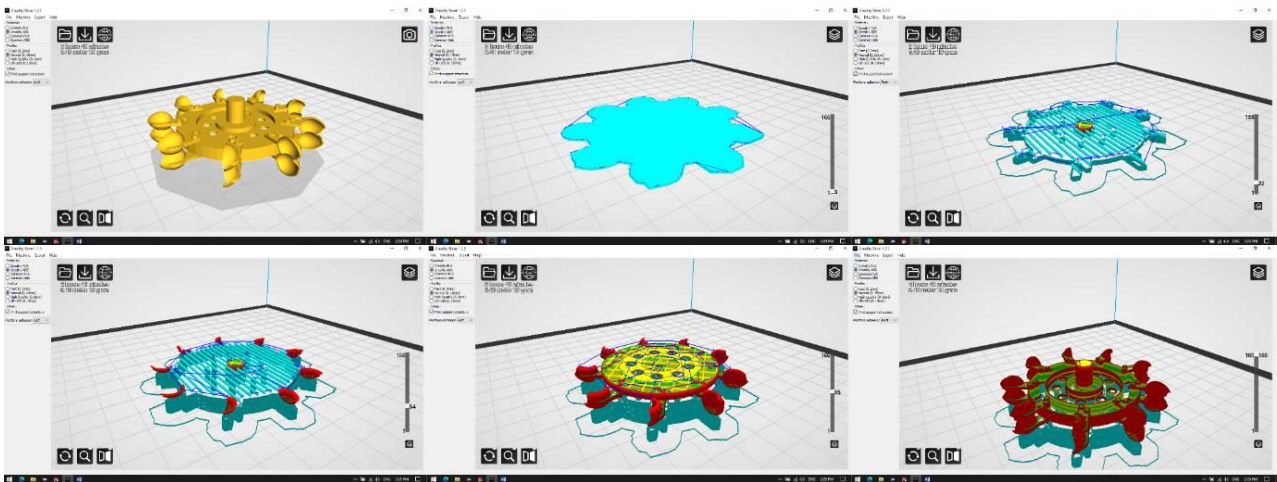


Figure 4.5 slicing the 3D model into layer-by-layer

4.6 Calculations

Design Calculation for Pelton Wheel Turbine

Considering the availability of head as

$$H = 250\text{m}$$

$$\text{Diameter of wheel, } D = 2.5\text{m}$$

$$(i) \text{ Velocity of Jet } (V_1) = C_v \sqrt{2gH}$$

$$V_1 = 0.98 * \sqrt{2 * 9.81 * 250}$$

$$V_1 = 68.63 \text{ m/s}$$

$$\text{Velocity of Jet} = 68.63 \text{ m/s}$$

$$(ii) \text{ Velocity of Wheel}$$

$$u = \Phi \sqrt{2gH}$$

$$\Phi = \text{Speed Ratio} = 0.43 \text{ to } 0.48$$

$$u = 0.45 \sqrt{2 * 9.81 * 250}$$

$$u = 31.5 \text{ m/s}$$

$$\text{Velocity of Wheel} = 31.5 \text{ m/s}$$

Angle of defraction of jet can be considered as 165°

Mean diameter of the wheel is taken as 2.5 m

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

$$N = \frac{60 * 31.5\text{m/s}}{\pi * (2.5)}$$

$$N = 240.6$$

$$N = 24.1$$

Jet Ratio

$$m = \frac{D}{d}$$

Usually Jet ratio is $m = 10$ to 12

$$\frac{D}{d} = 12$$

$$\frac{2.5}{d} = 12$$

$$d = \frac{2.5}{12}$$

$$d = 0.2m$$

Work done by the jet of water on bucket

$$W = \rho A V_1 [V_{W1} + V_{W2}]$$

$$A = \frac{\pi}{4} (d)^2$$

$$A = \frac{\pi}{4} (0.2)^2$$

$$A = 0.03m^2$$

$$\rho = 1000 \text{ (Density of Water)}$$

$$V_{W1} = V_1 = 68.6 \text{ m/s}$$

$$V_{r1} = v_1 - u_1$$

$$= 63.6 - 31.5$$

$$V_{r1} = 32.1 \text{ m/s}$$

From outlet velocity triangle

$$V_{r1} = V_{f2} = 32.1 \text{ m/s}$$

$$V_{W2} = V_{f2} \cos \Phi - u_2$$

$$= (32.1) (\cos 20^\circ - 31.5)$$

$$V_{W2} = 18.4 \text{ m/s}$$

$$W = 1000 * 0.03 * 68.6 [68.6 - 18.6]$$

$$W = 102900 \text{ W}$$

Power given to the turbine

$$P = \frac{W}{1000} \text{ KW}$$

$$P = \frac{102900}{1000}$$

$$P = 102.9 \text{ KW}$$

Hydraulic Efficiency

$$\eta_h = \frac{2 [V_{W1} \pm V_{W2}] * u}{(V_1)^2}$$

$$\eta_h = \frac{2 [68.6 - 18.4] * 31.5}{(68.6)^2}$$

$$\eta_h = 0.67$$

$$\eta_h = 67\%$$

V. RESULTS AND DISCUSSION

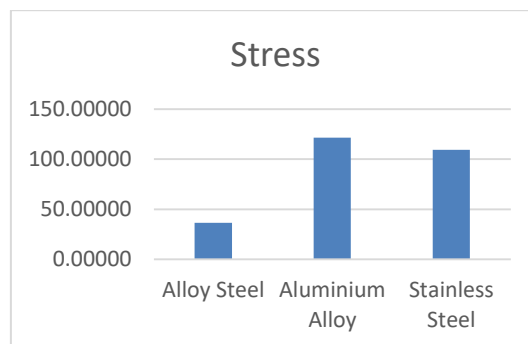
Pelton wheel is made up of steels, alloys that are injected with fiber glass reinforced plastic. Taking a different approach this time, we have tried using Alloy Steel, Aluminum Alloy, Stainless Steel as it can be recycled and reused to a large extent. All these materials are high resistance to corrosion and increased hardenability make it more advantageous for making a Pelton wheel. Three types of analysis have been conducted in SOLIDWORKS software to check stress, displacement and strain.



Figure 5.1 Final Prototype of Pelton Wheel

5.1 Equivalent Stress

The graphical representation of the comparison of equivalent stress of different materials when to subject to the pressure is shown below

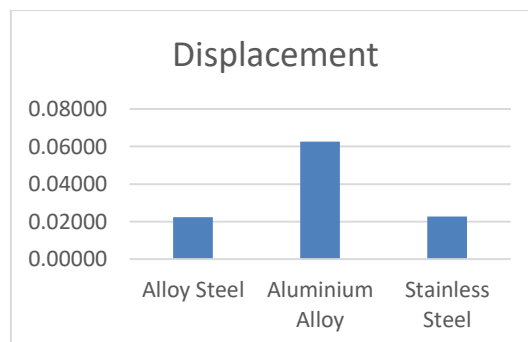


Graph 5.1 Equivalent Stress

The equivalent stress caused in Pelton Wheel of different materials (Alloy Steel, Aluminium Alloy, Stainless Steel) under the Pressure of 101325 N/m² (36.44000 N/mm², 121.70000 N/mm², 109.30000 N/mm²) are studied and compared among each other in the above graph. It is observed that the equivalent stress in Pelton Wheel is likely to be less in Alloy Steel Pelton Wheel on comparing to the other material Pelton Wheel.

5.2 Displacement

The graphical representation of the comparison of total deformation of different materials when to subject to the pressure is shown below.



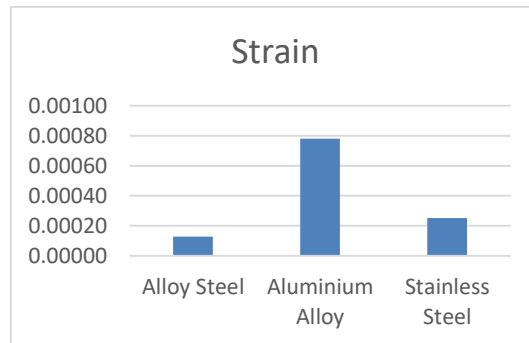
Graph 5.2 Total Displacement

The total Displacement caused in Pelton Wheel of different materials (Alloy Steel, Aluminum Alloy, Stainless Steel) under the Pressure of 101325 N/m² (0.02230mm, 0.06254mm, 0.02262mm) are studied and compared among each

other as shown in above graph. It is observed that the total Displacement in Pelton Wheel is likely to less in Alloy Steel Pelton Wheel on comparing to the other material Pelton Wheel.

5.3 Equivalent Strain

The graphical representation of the comparison of equivalent strain of different materials when to subject to the cycle of loads is shown below.



Graph 5.3 Equivalent Strain

The equivalent strain caused in Pelton Wheel of different materials (Structural Steel, Aluminium Alloy, Stainless Steel) under the Pressure of 101325 N/m² (0.00013, 0.00078, 0.00025) are studied and compared among each other as shown in the above graph. It is observed that the equivalent strain in Pelton Wheel is likely to less in Alloy Steel Pelton Wheel on comparing to the other material Pelton Wheel.

IV. CONCLUSIONS

In this project we have designed a Pelton wheel with number of buckets nine using Solid Works software and then CFD analysis is also done to the Pelton turbine to find out the flow of liquid. As here the materials considered are Alloy steel, Aluminium alloy and Stainless steel. As if we see the results of the analysis done cleared mentioned in the Results, total stress, strain and displacement is low for the alloy steel other than the two materials, as alloy steel has the best output in the life parameters and the life efficiency. So as per the results we can conclude that the alloy steels is the best suited material for the Pelton turbine bucket.

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