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DESIGN AND STRUCTURAL ANALYSIS OF PELTON WHEEL TURBINE BLADE

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Abstract: - In this project we have checked newly develop design known as hooped runner or advanced pelton wheel in which there are two hoops which supports the bucket from back side and giving it to rest on it. The new design is based on redistribution of the function of different parts of pelton wheel. In conventional runner the jet of water is directly strike to splitter of the bucket and transfers the force to it than buckets convert it into momentum by which the shaft is rotate and giving us power. Whereas in advanced pelton wheel bucket does not directly transport the force to the runner but transfer the force via these hoops and these hoops is connected to shaft and by that producing the power so due to hooped runner bucket act as simply supported beam comparing to simple pelton wheel so stress developed in hooped pelton is less due to this construction. In this project we want to achieve some critical data like stress developed. The project is directed towards the modeling of both traditional and advanced bucket pelton wheel in a 3D Cad tool called CATIA. The both the buckets have been analyzed in ANSYS WORKBENCH simulation tool by using two different materials namely CAST IRON,INCONEL 600,1020 steel and 1060 alloy under given loading conditions of 350N and 10000N.Among the both materials the best material is INCONEL600 as the stresses developed in INCONEL is Less under given loading condition.

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I TURBINE INTRODUCTION

A **turbine** (from the Latin turbo, a vortex, related to the Greek τύρβη, tyrbē, meaning "turbulence") is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be used for generating electrical power when combined with a generator or producing thrust, as in the case of jet engines. A turbine is a turbo machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. Early turbine examples are windmills and waterwheels.

Gas, steam, and water turbines have a casing around the blades that contains and controls the working fluid. Credit for invention of the steam turbine is given both to British engineer Sir Charles Parsons (1854–1931) for invention of the reaction turbine, and to Swedish engineer Gustaf de Laval (1845–1913) for invention of the impulse turbine. Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery.

The word "turbine" was coined in 1822 by the French mining engineer Claude Burdin from the Latin turbo, or vortex, in a memo, "Des turbines hydrauliques ou machines rotatoires à grande vitesse", which he submitted to the Académie royale des sciences in Paris. Benoit Fourneyron, a former student of Claude Burdin, built the first practical water turbine

Fig 1Turbine

1.1.1 Water turbine

Water turbine is a rotary machine that converts kinetic energy and potential energy of water into mechanical work. Water turbines were developed in the 19th century and were widely used for industrial power prior to electrical grids. Now they are mostly used for electric power generation. Water turbines are mostly found in dams to generate electric power from water kinetic energy.

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1.1.2 History of water turbine

Water wheels have been used for hundreds of years for industrial power. Their main shortcoming is size, which limits the flow rate and head that can be harnessed. The migration from water wheels to modern turbines took about one hundred years. Development occurred during the Industrial revolution, using scientific principles and methods. They also made extensive use of new materials and manufacturing methods developed at the time.

1.2 PELTON WHEEL TURBINE

The **Pelton wheel** is an impulse-type water turbine. It was invented by Lester Allan Pelton in the 1870s.[1][2] The Pelton wheel extracts energy from the impulse of moving water, as opposed to water's dead weight like the traditional overshot water wheel. Many variations of impulse turbines existed prior to Pelton's design, but they were less efficient than Pelton's design. Water leaving those wheels typically still had high speed, carrying away much of the dynamic energy brought to the wheels. Pelton's paddle geometry was designed so that when the rim ran at half the speed of the water jet, the water left the wheel with very little speed; thus his design extracted almost all of the water's impulse energy—which allowed for a very efficient turbine.

Fig 2 Pelton wheel turbine

1.3 Functioning

Nozzles direct forceful, high-speed streams of water against a rotary series of spoon-shaped buckets, also known as impulse blades, which are mounted around the circumferential rim of a drive wheel—also called a runner (see photo, 'Old Pelton wheel..'). As the water jet impinges upon the contoured bucket-blades, the direction of water velocity is changed to follow the contours of the bucket. Water impulse energy exerts torque on the bucket-and-wheel system, spinning the wheel; the water stream itself does a "u-turn" and exits at the outer sides of the bucket, decelerated to a low velocity. In the process, the water jet's momentum is transferred to the wheel and hence to a turbine. Thus, "impulse" energy does work on the turbine. For maximum power and efficiency, the wheel and turbine system is designed such that the water jet velocity is twice the velocity of the rotating buckets. A very small percentage of the water jet's original kinetic energy will remain in the water, which causes the bucket to be emptied at the same rate it is filled, (see conservation of mass) and thereby allows the high-pressure input flow to continue uninterrupted and without waste of energy. Typically two buckets are mounted side-by-side on the wheel, which permits splitting the water jet into two equal streams (see photo). This balances the side-load forces on the wheel and helps to ensure smooth, efficient transfer of momentum of the fluid jet of water to the turbine wheel.

II LITERATURE REVIEW

Bilal Abdullah Nasirdescribes the design of pelton wheel for obtaining maximum efficiency for all parameter. These parameters are turbine specific efficiency, number of bucket required, number of jets and the dimension of jet, nozzle dimension, turbine power, torque, runner speed, bucket dimension and during various conditions. In this paper to improve the maximum efficiency different steps of design included such as for preparing the site data included the head race and tail race of plant. Raj Kumar Kapooriapresented some modification by which the pelton wheel can be used for heavy discharge and at low head. Comparatively a heavy generator can be run under low head and heavy discharge due to this modification. The water potential as well as kinetic energy both is consumed by the runner wheel. In this turbine the bucket of pelton wheel is modified and the modification is adding extra bucket-cups it means it like as cattle pot where the water pouring is done at top opening and discharges at another opening.Loice Gudukeya & Ignatio Madamhirepresents the improvement of pelton wheel turbine on the power out of plant while keeping the cost of project in the acceptable range and also works on the parameters such as surface texture. Material used and process of fabrication by which improves the efficiency up to 20 to 25 percent for micro hydro power plants

New concept

All common water machines until the late 19th century (including water wheels) were basically reaction machines; water pressure head acted on the machine and produced work. A reaction turbine needs to fully contain the water during energy transfer.

In 1866, California millwright Samuel Knight invented a machine that took the impulse system to a new level.[5][6] Inspired by the high pressure jet systems used in hydraulic mining in the gold fields, Knight developed a bucketed wheel which captured the energy of a free jet, which had converted a high head (hundreds of vertical feet in a pipe or penstock) of water to kinetic energy. This is called an impulse or tangential turbine. The water's velocity, roughly twice the velocity of the bucket periphery, does a u-turn in the bucket and drops out of the runner at low velocity.

In 1879, Lester Pelton, experimenting with a Knight Wheel, developed a Pelton wheel (double bucket design), which exhausted the water to the side, eliminating some energy loss of the Knight wheel which exhausted some water back against the center of the wheel. In about 1895, William Doble improved on Pelton's half-cylindrical bucket form with an elliptical bucket that included a cut in it to allow the jet a cleaner bucket entry. This is the modern form of the Pelton turbine which today achieves up to 92% efficiency. Pelton had been quite an effective promoter of his design and although Doble took over the Pelton company he did not change the name to Doble because it had brand name recognition.Turgo and cross-flow turbines were later impulse designs.

III PROJECT OVER VIEW

3.1 OBJECTIVE:

The objectives of this project are:

1. To study the static analysis capacity of the pelton wheel turbine bucket.

2. To determine the structural analysis pelton wheel turbine bucket by using different materials.

3.2 SCOPE of the project :

The scopes of this proposed project are:

1. To generate 3-dimensional geometry model in catia workbench of the pelton wheel bucket.

2. To perform structural analysis on the model to determine the stress, deformation, shear stress of the component under the static load conditions

3. To compare analysis between four different materials of pelton wheel turbine bucket

3.3 PROBLEM STATEMENT:

Improper material leads the failure and damage due to excessive forces at that time need proper material of pelton wheel bucket, grey cast iron formed corrosion, cracks, generally using steel and alluminium materials we are choosing the inconel material because of high stiffness, low stresses, deformation Inconel is a family of austenitic nickel-chromium-based superalloys. These alloys are oxidation- and corrosion-resistant materials well suited for service in extreme environments subjected to pressure and heat. When heated, it forms a thick, stable, passivating oxide layer protecting the surface from further attack. This material retains strength over a wide temperature range, attractive for high temperature applications.

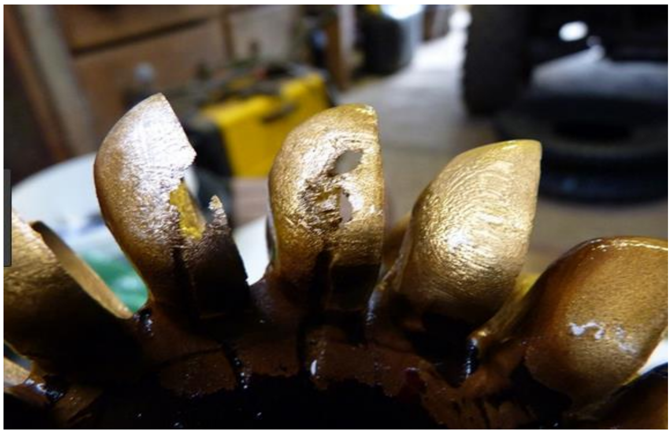

Fig 3 Material damage

3.4 OBJECTIVE

The objective of this project is to make a 3D model of the pelton wheel bucket and study the static behaviour of the pelton wheel tubine by performing the finite element analysis.3D modelling software (catia v5) was used for designing and analysis software (ANSYS) was used for analysis.

3.5 Methodology

The methodology followed in the project is as follows:

• Create a 3D model of the pelton wheel turbine bucket using parametric software catia v5.

• Convert the surface model into IGS and import the model into ANSYS to do analysis.

• Perform static analysis analysis on the pelton wheel bucket

• Finally it was concluded which material is the suitable for pelton wheel bucket

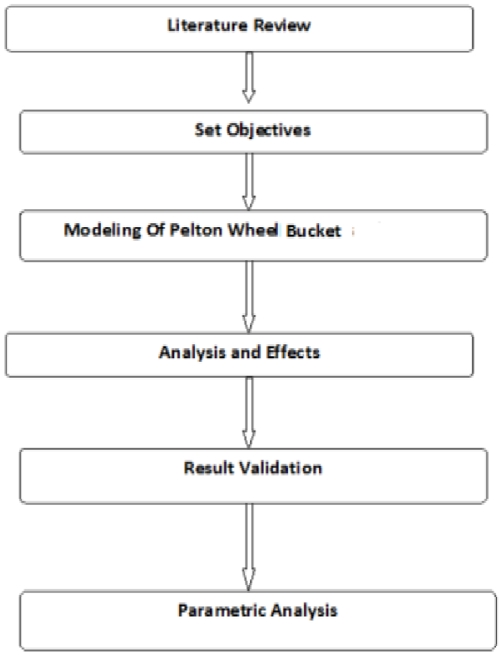

Fig 4 Methodology flow chart

Material properties:

3.5.1 GREY CAST IRON:

Gray iron, or **grey cast iron**, is a type of cast iron that has a graphitic microstructure. It is named after the gray color of the fracture it forms, which is due to the presence of graphite. It is the most common cast iron and the most widely used cast material based on weight. It is used for housings where the stiffness of the component is more important than its tensile strength, such as internal combustion engine cylinder blocks, pump housings, Turbines, valve bodies, electrical boxes, and decorative castings. Grey cast iron's high thermal conductivity and specific heat capacity are often exploited to make cast iron cookware and disc brake rotors.

Tab 1 Grey cast iron properties

Material Property	Unit	Grey Cast Iron
Density	Kg/m3	7200
Young's modulus	Pa	1.1E+11
Poisson's Ratio	-	0.28
Bulk Modulus	Pa	8.33E+10
Shear Modulus	Pa	4.29E+10

3.5.2 Inconel 600

Inconel is a family of austenitic nickel-chromium-based superalloys.

Inconel alloys are oxidation-corrosion-resistant materials well suited for service in extreme environments subjected to pressure and heat. When heated, Inconel forms a thick, stable, passivating oxide layer protecting the surface from further attack. Inconel retains strength over a wide temperature range, attractive for high temperature applications where aluminum and steel would succumb to creep as a result of thermally induced crystal vacancies. Inconel's high temperature strength is developed by solid solution strengthening or precipitation hardening, depending on the alloy.

Tab 2 Inconel 600 properties

Material	Inconel 600
Density	8.4 g/cc
Young's modulus	207Gpa
Poisson's ratio	0.33
Tensile strength ultimate	655Mpa
Tensile strength yield	310 MPa
Elongation break	45%

Inconel alloys are typically used in high temperature applications. Common trade names for Inconel Alloy 625 include: Inconel 625, Chronin 625, Altemp 625, Haynes 625, Nickelvac 625 and Nicrofer 6020

3.5.3 1020 STEEL

Carbon steel is a steel with carbon content up to 2.1% by weight. The definition of carbon steel from the American Iron and Steel Institute (AISI) states:

Steel is considered to be carbon steel when: no minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, t ungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect;

- The specified minimum for copper does not exceed 0.40 percent;
- or the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.

The term "carbon steel" may also be used in reference to steel which is not stainless steel; in this use carbon steel may include alloy steels.As the carbon percentage content rises, steel has the ability to become harder and stronger through heat treating; however, it becomes less ductile. Regardless of the heat treatment, a higher carbon content reduces weldability. In carbon steels, the higher carbon content lowers the melting point

Tab 3 1020 steel properties

Material	1020 STEEL
Density	7.85 g/cc
Young's modulus	140Gpa
Poisson's ratio	0.29
Tensile strength ultimate	394.72Mpa
Tensile strength yield	294.74 MPa
Elongation break	0.365

3.5.4 1060 ALLOY Carbon steel

Carbon steel is a popular choice for rough use knives. Carbon steel tends to be much tougher and much more durable, and easier to sharpen than stainless steel. They lack the chromium content of stainless steel, making them susceptible to corrosion. Carbon steels have less carbon than typical stainless steels do, but it is the main alloy element. They are more homogeneous than stainless and other high alloy steels, having carbide only in very small inclusions in the iron. The bulk material is harder than stainless, allowing them to hold a sharper and more acute edge without bending over in contact with hard materials. But they dull by abrasion quicker because they lack hard inclusions to take the friction. This also makes them quicker to sharpen. Carbon steel is well known to take a sharper edge than stainless

Tab 4 1060 steel properties

Material	1060 ALLOY
Density	7.85 g/cc
Young's modulus	200Gpa
Poisson's ratio	0.30
Tensile strength ultimate	485Mpa
Tensile strength yield	620 Mpa
Elongation break	10%

Density	7.85 g/cc
Young's modulus	200Gpa
Poisson's ratio	0.30
Tensile strength ultimate	485Mpa
Tensile strength yield	620 Mpa
Elongation break	10%

3.6 DESIGN STEPS OF A PELTON BUCKET

Considering the initial operating condition of the turbine; the runner bucket assembly is stationary at initial stage. The water jet leaves the nozzle at a very high velocity and strikes the bucket with high kinetic energy. During the normal running of a pelton turbine a continuous jet of water at varying speed is maintained for the uninterrupted rotation of the runner. However it is the first jet of water that strikes the bucket which has the maximum impact on the bucket profile, this is because the first water jet has to overcome the inertia forces of the runner. In fact it is the first water jet impact which produces the rotational momentum and torque required for the rotation of the runner. This journal deals with the construction of a pelton bucket for considering first impact force of water jet.

Assumptions:

Net head is taken as 45 m, 2) Rotational speed is taken as 1200 rpm, 3) Flow rate is taken to be 6 liters per second, 4) the bucket is stationary, 5) the bucket is designed at maximum efficiency.

Bucket design procedure:

Calculations:-

BASIC BUCKET DESIGN

Bucket is made of elliptical section as in figure. The longitudinal section of the one half of the bucket is an ellipse with axes 52mm and 29mm, similarly the middle transverse section is an ellipse with axes 58mm and 29mm.[2]

Calculation

Velocity of jet $(V_{jet}) = \sqrt{2gH}$

$$= \sqrt{2 \times 9.81 \times 45} = 29.7\ {}^{m}/_{s}$$

Bucket speed (U) $= 0.46V_{jet}$

$$= 13.6\ {}^{m}/_{s}$$

Runner diameter $(D_{run}) = \frac{60U}{\pi N}$

$$= \frac{60 \times 13.66}{\pi \times 1200}$$

Jet diameter $(D_{jet}) = \frac{D_{run}}{10} = 0.0217\text{m}$

Moment arm length $= 0.195 \times D_{run} = 0.04321\text{m}$

Depth of bucket (t) $= 0.9 \times D_{jet} = 0.01953\text{m}$

Width of bucket (b) $= 2.6 \times D_{jet} = 0.058\text{m}$

Height of bucket (h) $= 2.4 \times D_{jet} = 0.052\text{m}$

Width of bucket opening (a) $= D_{jet} = 0.021\text{m}$

The force of water jet on bucket=2 x 1000 x Q x(V_{jet}) = 349.32N

Tab 5 Parameters

PARAMETERS	UNIT	DIMENSION
Head	Meter	45
Rotational speed	Rotations per minute	1200
Velocity of jet	Meter/second	29.7
Flow rate	Liters per second	6
Bucket speed	Meter/second	13.6
Runner diameter	millimeter	217
Jet diameter	millimeter	21.7
Shaft length	millimeter	42.31
Depth of bucket	millimeter	19.53
Width of bucket	millimeter	58
Height of bucket	millimeter	52
Force of water jet on bucket	Newton	262

IV DIMENSIONS AND DESIGN PROCEDURE IN CATIA:

Go to the sketcher work bench create the ellipse after go to the part design workbench go to plane create the offset distance with 52 mm we are taking dimensions width of bucket is 58mm and depth of bucket is 19.52 . we are creating by using multi section, after create the buckets apply shell option and again go to the sketcher create the length of bucket shafts using pad option as shown below figure

Fig 5 Pelton wheel bucket in catia work bench

V INTRODUCTION TO ANSYS

ANSYS is a large-scale multipurpose finite element program developed and maintained by ANSYS Inc. to analyze a wide spectrum of problems encountered in engineering mechanics**.**

5.1 PROGRAM ORGANIZATION:

The ANSYS program is organized into two basic levels:

- Begin level
- Processor (or Routine) level

The Begin level acts as a gateway into and out of the ANSYS program. It is also used for certain global program controls such as changing the job name, clearing (zeroing out) the database, and copying binary files. When you first enter the program, you are at the Begin level.

VI FINITE ELEMENT METHOD

6.1 INTRODUCTION

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called "Finite Elements". The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called "Nodes" or "Nodal Points". Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called "shape functions". This will represent the displacement with in the element in terms of the displacement at the nodes of the element.

The Finite Element Method is a mathematical tool for solving ordinary and partial differential equations. Because it is a numerical tool, it has the ability to solve the complex problems that can be represented in differential equations form. The applications of FEM are limitless as regards the solution of practical design problems.

6.2ANALYSIS PROCEDURE IN ANSYS:

Designed component in catia workbench after imported into ansys workbench now select the steady state thermal analysis .

1.ENGINEEERING MATERIALS (MATERIAL PROPERTIES).
2.CREATE OR IMPORT GEOMENTRY.
3.MODEL(APPLY MESHING).
4.SET UP(BOUNDARY CONDITIONS)
5.SOLUTION
6.RESULTS

6.3 STATIC STRUCTURAL ANALYSIS

The static structural analysis calculates the stresses, displacements, shear stress and forces in structures caused by a load that does not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that the loads and the structure's response are assumed to change slowly with respect to time. A static structural load can be performed using the ANSYS WORKBENCH solver. The types of loading that can be applied in a static analysis include:

6.4 Meshing

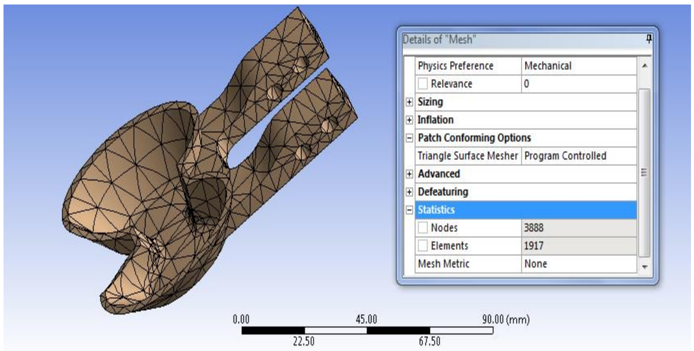

Fig 6 Meshing of pelton wheel buket

Nodes =3888

Elements=1917

6.5 Boundary conditions :350N

We have applied 350 N of force on bucket as shown below figure

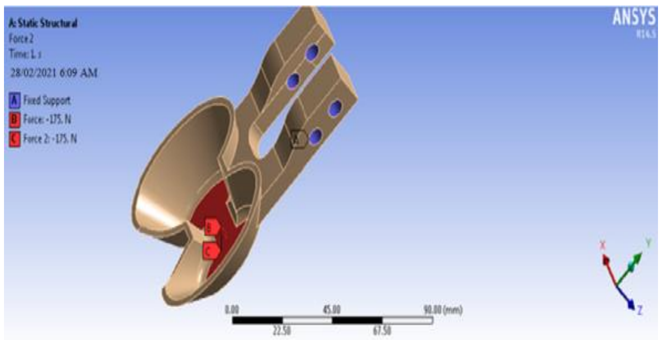

Fig 7 Boundary condition on pelton wheel bucket

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VII RESULTS AND DISCUSSION

7.1 STATIC ANALYSIS RESULTS:

This analysis is performed to find Structural parameters such as Stresses, Deformation, shear stress. Here we observed results on four materials namely inconel 600, steel1020,steel 1060 steel and grey cast iron as shown below figures

7.1.1 Inconel 600 material:

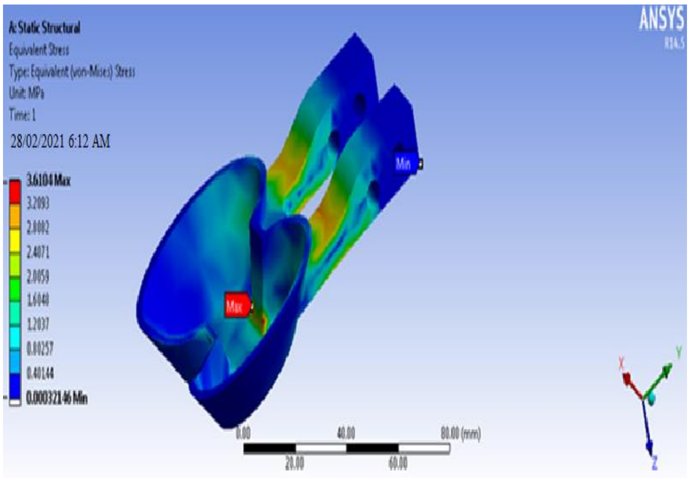

Fig 8 Stress on inconel 600 material

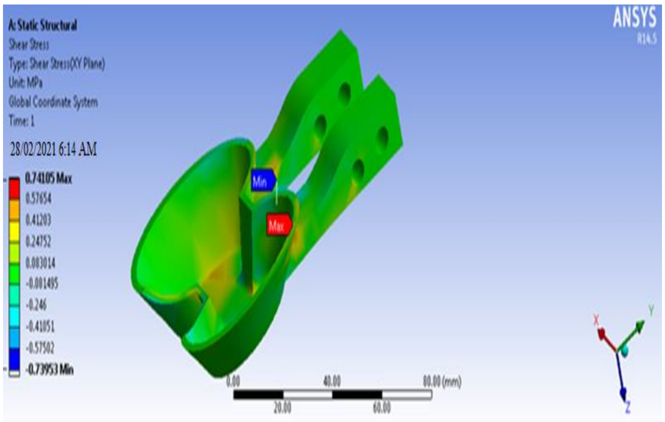

Fig 9 Shear stress on inconel 600 material

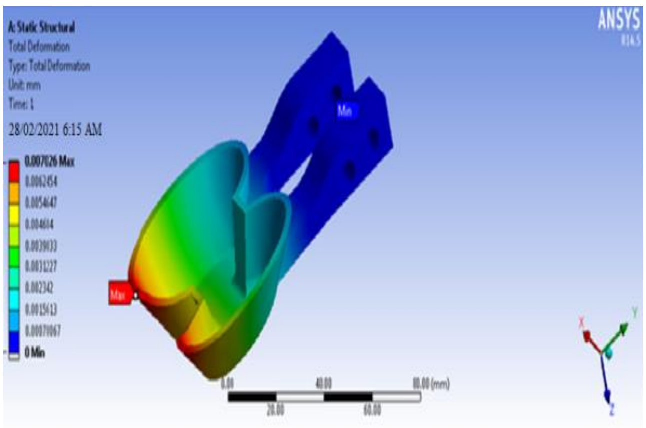

Fig 10 Total deformation on inconel 600 material

7.1.2 Cast iron

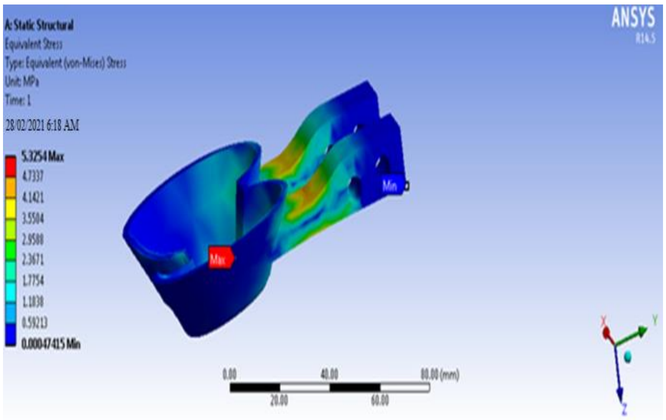

Fig 11 Stress on cast iron

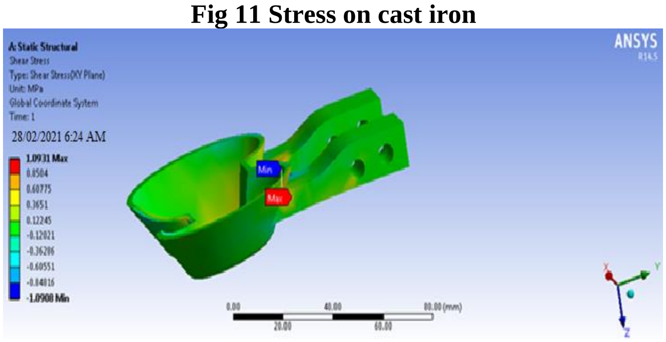

Fig 12 Shear stress on cast iron

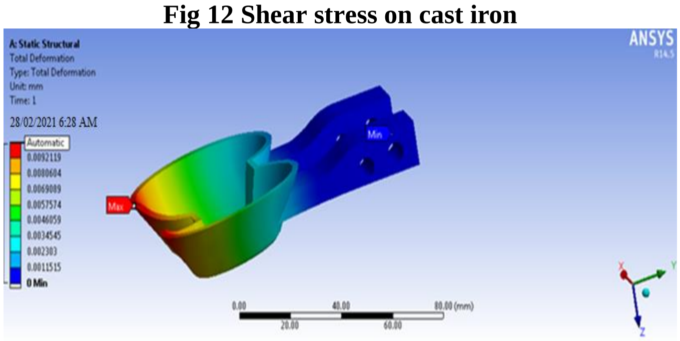

Fig 13 Total deformation on cast iron

Tab 6 Final results

Material	Stress(MPa)	Shear stress(MPa)	Total deformation(mm)
Inconel 600	3.6104	0.74105	0.007026
Grey cast iron	5.3254	1.0931	0.0095054
1020 steel	4.3325	0.88926	0.0084312
1060 steel	5.0546	1.0375	0.0098364

7.2 Graphs:

7.2.1 Stress graph

This graph shows the different maximum stress values in different materials, inconel 600) (3.6104)material has least shear stress value compared to another materials as shown in the graph 1

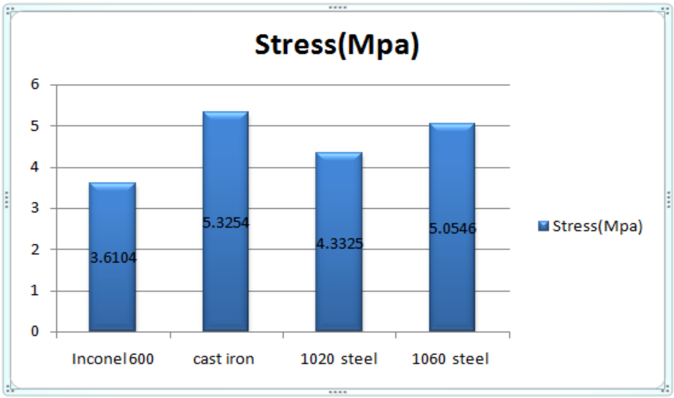

Fig 14 stress graph

7.2.2 Shear stress graph

This graph shows the different maximum shear stress values in different materials, inconel 600(0.74105) material has least shear stress value compared to another materials as shown in the graph 2

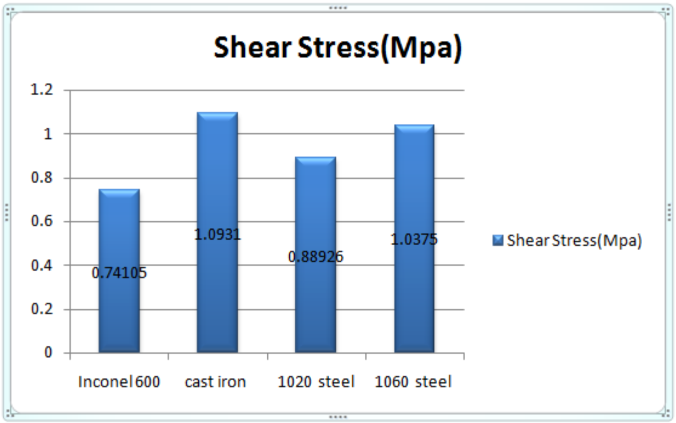

Fig 15 shear stress graph

7.2.3 Total deformation graph

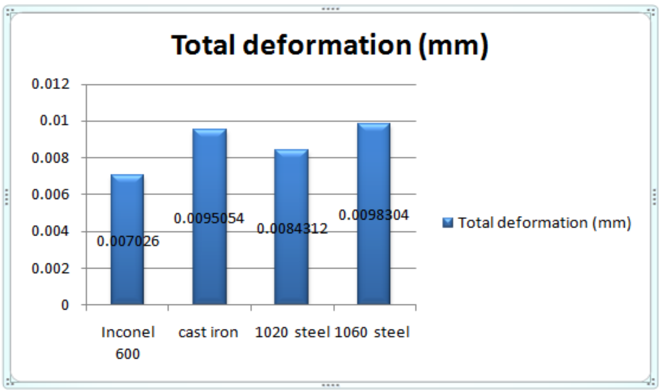

Fig 16 Total deformation graph

This graph shows the maximum deformation values for different materials, inconel 600 (0.007026)material has least maximum deformation value compared to another materials as shown in the graph 3

VIII CONCLUSION

Modeling of Pelton wheel bucket is done by using CATIAV5 Software and then the model is imported into ANSYS Software for Structural analysis on the Pelton wheel bucket to check the quality of materials such as, Inconel 600,GREY CAST IRON, STEEL 1020,STEEL 1060, From the investigation, the obtained Von-misses stresses, Shear stress, deformation for the materials, respectively Compared to all materials these materials inconel 600 material have less stresses, deformations, shear stress. Finally structural analysis is done and concluded that inconel 600 as good material because of Inconel alloys are oxidation-corrosion-resistant materials well suitable for service in extreme environments subjected to pressure and heat. When heated, Inconel forms a thick, stable, passivating oxide layer protecting the surface from further attack. Inconel retains strength over a wide temperature range, than inconel is suitable material for pelton wheel bucket

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