ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

DESIGN AND ANALYSIS OF PELTON WHEEL

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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 SOLIDWORKS 2014. The both the buckets have been analyzed in SOLIDWORKS simulation tool by using two different materials namely 1020 steel and 1060 alloy under given loading conditions of 269N and 10000N.Among the both materials the best material is 1020 steel as the stresses developed in 1020 steel is less than the material yield strength under given loading condition.

Key Words: ***Pelton wheel, Yield, Stress, Shaft, 3D CAD***

INTRODUCTION

Turbine

A turbine, from the Greek ("turbulence"), is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. 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 usually have a casing around the blades that contains and controls the working fluid. Credit for invention of the steam turbine is given both to the 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 memoir, "Des turbines hydrauliques ou machines rotatoires à grande vitesse", which he submitted to the Académie royale des sciences in Paris.[3] Benoit Fourneyron, a former student of Claude Burdin, built the first practical water turbine.

Types of turbines

Steam turbines are used for the generation of electricity in thermal power plants, such as plants using coal, fuel oil or nuclear power. They were once used to directly drive mechanical devices such as ships' propellers (for example the *Turbinia*, the first turbine-powered steam launch) but most such applications now use reduction gears or an intermediate electrical step, where the turbine is used to generate electricity, which then powers an electric motor connected to the mechanical load. Turbo electric ship machinery was particularly popular in the period immediately before and during World War II, primarily due to a lack of sufficient gear-cutting facilities in US and UK shipyards.

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Classification of hydraulic turbines

The hydraulic turbines are classified according to the type of energy available at the inlet of the turbine, direction of flow through the vanes, head at the inlet of the turbine and specific speed of the turbines. Thus the following are the important classification of the turbine:

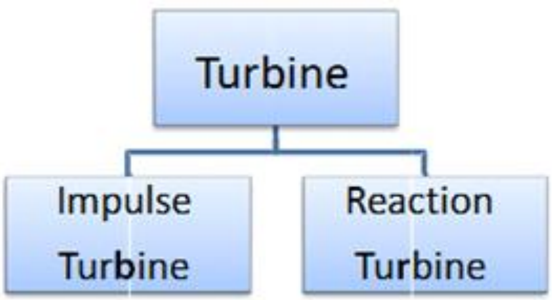

Figure 1: Classification according to action of fluid on moving blades

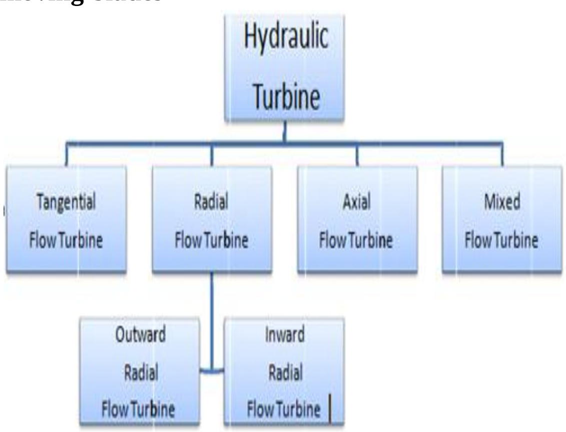

Figure 2: Classification according to direction of flow of fluid in the runner

PELTON WHEEL

The Pelton wheel is an impulse type water turbine. It was invented by Lester Allan Pelton in the 1870s. 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 ½ 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.

The pelton turbine operating principle

The Pelton turbine is an impulse turbine that only converts kinetic energy of the flow into mechanical energy. The transfer of the total energy from the nozzle exit to the downstream Reservoir occurs at atmospheric pressure. The jet stemming from the injector impinges on buckets, located at the periphery of a wheel.

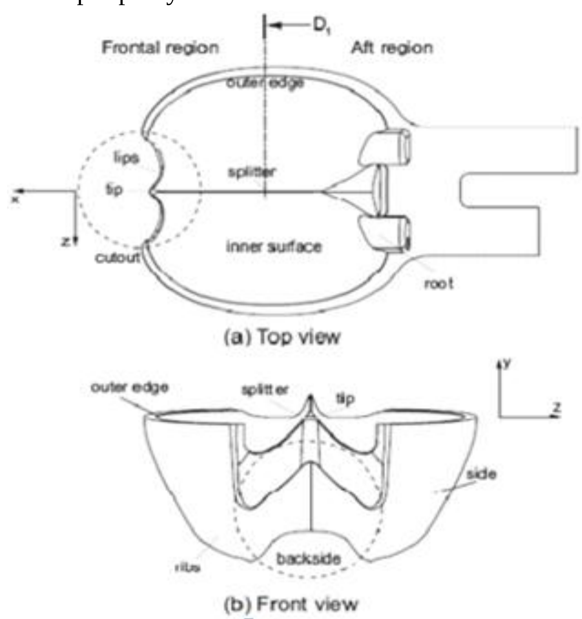

Figure 3: Buckets Geometric Definitions

Layout of pelton wheel

The Pelton wheel or Pelton turbine is a tangential flow impulse turbine. The water strikes the bucket along the tangent of the runner. The energy available at the inlet of the turbine is only kinetic energy. The pressure at the inlet and outlet of the turbine is atmosphere. This turbine is used for high heads and is named after L.A. Pelton, an American Engineer. The water from the reservoir flows through the penstocks at the outlet of which a nozzle is fitted. The nozzle increases the kinetic energy of the water flowing through the penstock. At the outlet of the nozzle, the water comes out in the form of a jet and strikes the buckets (vanes) of the runner. The main parts of the Pelton turbine are Nozzle and flow regulating arrangement (spear), Runner and buckets, Casing, and Breaking jet.

Efficiencies of turbine

The following are the important Efficiencies of a turbine.

(A) Hydraulic efficiency (η_h)

(B) Mechanical efficiency (η_m)

(C) Volumetric efficiency (η_v)

(D) Overall efficiency (η_o)

Hydraulic efficiency (η_h)

It is defined as the ratio of the power given by water to the runner of a turbine (runner is a rotating part of a turbine and on the runner vanes are fixed) to the power supplied by the water at the inlet of the turbine. The power at the inlet of the turbine is more and this power goes decreasing as the water flow over the vanes of the turbine due to hydraulic losses as the vanes are not smooth. Hence the power delivered to the runner of the turbine will be less than the power available at the inlet of the turbine. Thus mathematically, the hydraulic efficiency of the turbine is written as

$$\eta_h = \frac{\text{Power delivered to the runner}}{\text{Power supplied at the inlet}} = \frac{R.P.}{W.P.}$$

$$= \frac{W\,[V_{w1} \pm V_{w2}]\,u}{g\;1000}\ \text{kW}$$

Power supplied at inlet of turbine and also called water power

$$W.P. = \frac{\rho\, g\, Q\, H}{1000}\ \text{kW}$$

Mechanical efficiency (η_m)

The power delivered by water to the runner of turbine is transmitted to the shaft of the turbine. Due to mechanical losses, the power available at the shaft of the turbine is less than the power delivered to the runner of a turbine. The ratio of the power available at the shaft of the turbine (known as S.P. or B.P.) the power delivered to the runner is define as mechanical efficiency. Hence, mathematically, it is written as:

$$\eta_m = \frac{\text{Power at the shaft of the turbine}}{\text{Power delivered by water to the runner}} = \frac{S.P.}{R.P.}$$

Volumetric efficiency (η_v)

The volume of the water striking the runner of a turbine is slightly less than the volume of the water supply to the turbine. Some of the volume of the water is discharged to the tailrace without striking the runner of the turbine. Thus the ratio of the volume of the water actually striking the runner to the volume of water supplied to the turbine is defined as volumetric efficiency. It is written as

$$\eta_v = \frac{\text{volume of water actually striking the runner}}{\text{voleme of water supplied to the turbine}}$$

Overall efficiency (η_o)

It is define as the ratio of power available at the shaft of the turbine to the power supplied by the water at the inlet of the turbine. It is written as

$$\eta_o = \frac{\text{power available at the shaft of the turbine}}{\text{power supplied at the inlet of the turbine}}$$

$$= \frac{S.P.}{W.P.} \qquad = \frac{S.P.}{R.P}\,\frac{R.P}{W.P.} \qquad = \eta_m \times \eta_h$$

Force calculation

Here we shown sample force calculation for one flow rate only, whole data including readings and results at different flow rate & different opening is given in Appendix-A. The jet of water is comes out from nozzle and strikes on splitter of the bucket. The force which transferred by jet to the bucket is calculated below

Flow rate Q = 10×10^{-3} m3/sec

Runner mean diameter D = 360 mm

Head H = 40 m

Speed N = 680 rpm

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$$V_1 = Kv_1\sqrt{2gh}$$
$$= 0.985\times\sqrt{2\times 9.81\times 40}$$
$$= 27.54 \text{ m/sec}$$
$$U_1 = \frac{\pi DN}{60} = \frac{\pi \times 360\times 10^{-3}\times 680}{60} = 12.817 \text{ m}^3\text{/sec}$$

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$$U_1 = \frac{\pi DN}{60} = \frac{\pi \times 360\times 10^{-3}\times 680}{60} = 12.817 \text{ m}^3\text{/sec}$$

V_{w1} = v1-u1 = 14.773 m/sec
V_{w2} = 0.85 × Vw1 = 12.55705 m/sec
V_{u2} = u2 – Vw2 cos 15 = 0.68786 m/sec
So, Force applied by jet on bucket
Fu = ρ × Q × (Vu1-Vu2)
= (Vu1 – Vu2)
= 26.912
Fu = 269 N

MODELING OF PELTON WHEEL

Solid works

Solid Works is mechanical design automation software that takes advantage of the familiar Microsoft Windows graphical user interface. It is an easy-to-learn tool which makes it possible for mechanical designers to quickly sketch ideas, experiment with features and dimensions, and produce models and detailed drawings.

Introduction to solid works

Solidworks mechanical design automation software is a feature-based, parametric solid modeling design tool which advantage of the easy to learn windows graphical user interface. We can create fully associate 3-D solid models with or without while utilizing automatic or user defined relations to capture design intent. Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allow them to capture design intent.

Layer-cake approach

The layer-cake approach builds the part one piece at a time, adding each layer, or feature, onto the previous one.

Potter's wheel approach

The potter's wheel approach builds the part as a single revolved feature. As a single sketch representing the cross section includes all the information and dimensions necessary to make the part as one feature.

Manufacturing approach

The manufacturing approach to modeling mimics the way the part would be manufactured. For example, if the stepped shaft was turned a lathe, we would start with a piece of bar stock and remove material using a series of cuts.

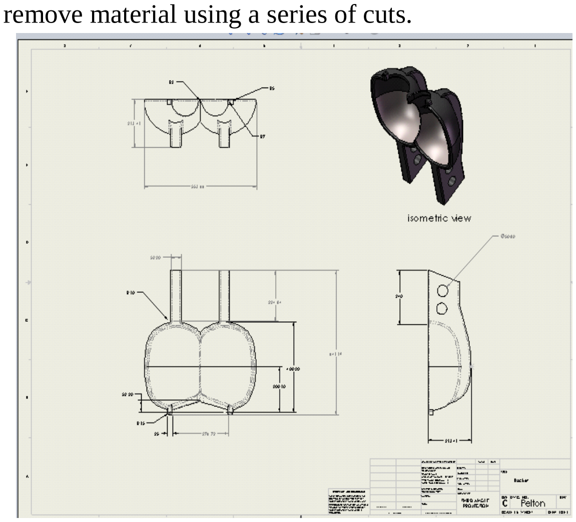

Figure 4: dimensions of the Traditional Bucket

STRESS ANALYSIS OF SIMPLE AND ADVANCED PELTON WHEEL

The stress analyses of the traditional and hooped runner carried out and compare stress level. Models of traditional and hooped runner have same number of buckets and tip diameter which is used in present numerical simulation, models showing in this chapter.

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Modeling

In a traditional runner the bucket is work as a cantilever beam subjected to the force generated by the jet. These alternated forces lead to fatigue stresses. Due to the geometry of the bucket, the seat of these stresses is in the connection radius between the rim and the centre edge in the upper part of the bucket thereby generating traction stresses. In a hooped runner the arms are worked as an embedded beam. By this type of design decrease stress at a most failure zone and the transformation of traction stresses by compression stresses, as the geometry of the discharge radius is inverted. The hoop is connected with buckets on a runner where buckets are fitted.

Introduction to solidworks simulation:

SolidWorks Simulation is a design analysis system fully integrated with SolidWorks. SolidWorks Simulation provides simulation solutions for linear and nonlinear static, frequency, buckling, thermal, fatigue, pressure vessel, drop test, linear and nonlinear dynamic, and optimization analyses.Powered by fast and accurate solvers, SolidWorks Simulation enables you to solve large problems intuitively while you design. SolidWorks Simulation comes in two bundles: SolidWorks Simulation shortens time to market by saving time and effort in searching for the optimum design.

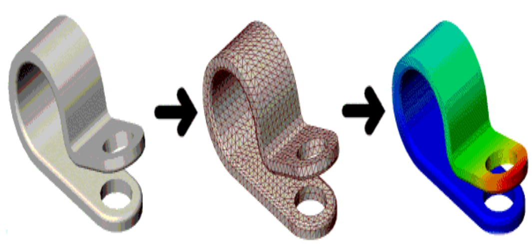


Figure 6: Simulation example

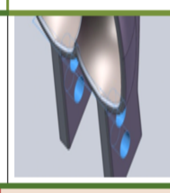
Benefits of Simulation:

After building your model, you need to make sure that it performs efficiently in the field. In the absence of analysis tools, this task can only be answered by performing expensive and time-consuming product development cycles.

Simulation

Properties	
Name:	1060 Alloy
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	2.75742e+007 N/m^2
Tensile strength:	6.89356e+007 N/m^2
Elastic modulus:	6.9e+010 N/m^2
Poisson's ratio:	0.33
Mass density:	2700 kg/m^3
Shear modulus:	2.7e+010 N/m^2
Thermal expansion coefficient:	2.4e-005 /Kelvin

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: 4 face(s) Type: Fixed Geometry
Load name	**Load Image**	**Load Details**
Force-1		Entities: 4 face(s) Type: Apply normal force Value: 269 N Phase Angle: 0 Units: deg

Mesh Information - Details

Total Nodes	19027
Total Elements	10625
Maximum Aspect Ratio	24.733
% of elements with Aspect Ratio < 3	90.6
% of elements with Aspect Ratio > 10	0.574
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:22
Computer name:	SANDEEP-PC

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Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	22.6674 mm
Tolerance	1.13337 mm
Mesh Quality	High

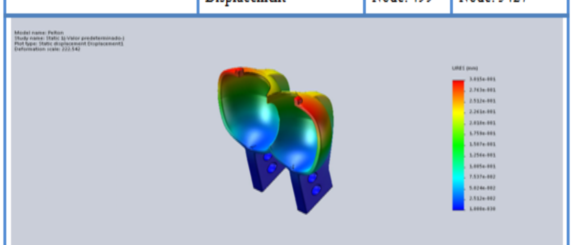
A factor of safety less than 1 at a location indicates that the material at that location has failed. A factor of safety of 1 at a location indicates that the material at that location has just started to fail .So our design is safe.

Simulation of traditional bucket using 1060 alloy applying 10000n load

Performing same analysis on bucket by varying load of 10000N the results obtained are as follows

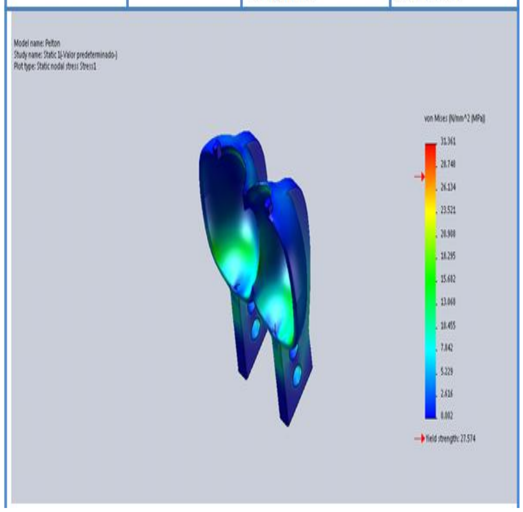
Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.0023459 N/mm^2 (MPa) Node: 11847	31.3609 N/mm^2 (MPa) Node: 9737

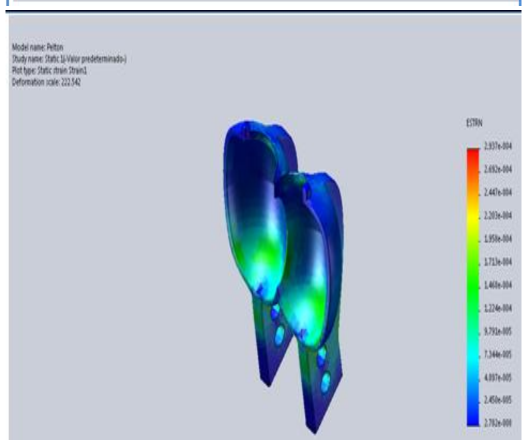
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 499	0.30146 mm Node: 5427



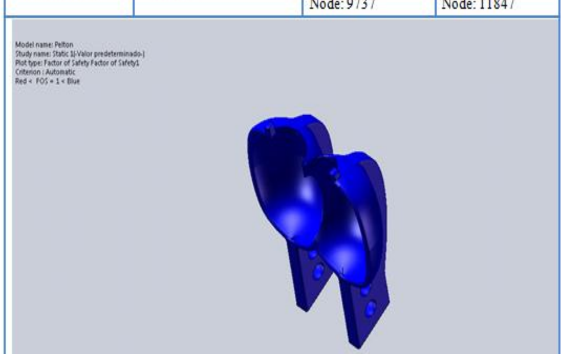
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.78195e-008 Element: 9287	0.000293662 Element: 6899

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.0023459 N/mm^2 (MPa) Node: 11847	31.3609 N/mm^2 (MPa) Node: 9737





Name	Type	Min	Max
Factor of Safety1	Automatic	0.879254 Node: 9737	11754.2 Node: 11847



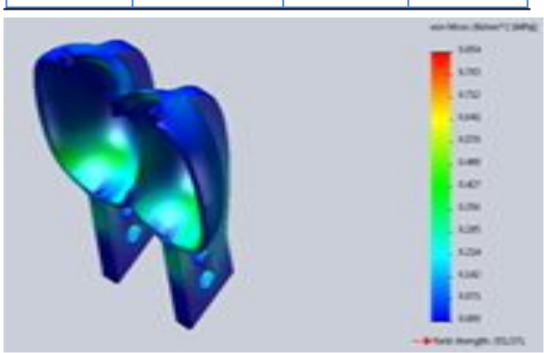
A factor of safety less than 1 at a location indicates that the material at that location has failed.A factor of safety of 1 at a location indicates that the material at that location has just started to fail. A factor of safety greater than 1 at a location indicates that the material at that location is safe. So our design is not safe.

Simulation of traditional bucket using 1020 steel applying 269n load : Performing same analysis on bucket by varying load of 10000N the results obtained are as follows

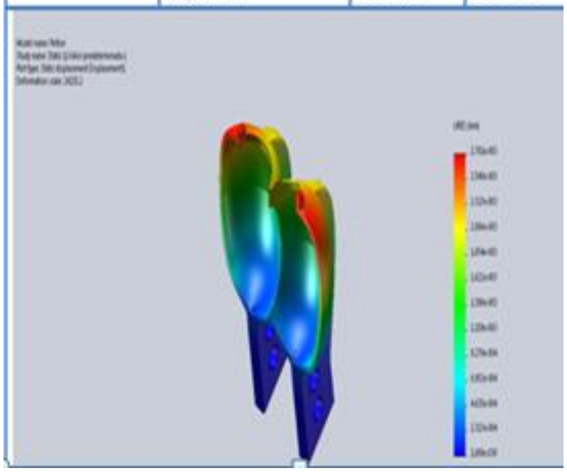
Material Properties

Model Reference	Properties		Components
	Name:	AISI 1020	SolidBody 1(61/64 (0.95313) Diameter Hole1)(Pelton)
	Model type:	Linear Elastic Isotropic	
	Default failure criterion:	Max von Mises Stress	
	Yield strength:	3.51571e+008 N/m^2	
	Tensile strength:	4.20507e+008 N/m^2	
	Elastic modulus:	2e+011 N/m^2	
	Poisson's ratio:	0.29	
	Mass density:	7900 kg/m^3	
	Shear modulus:	7.7e+010 N/m^2	
	Thermal expansion coefficient:	1.5e-005 /Kelvin	

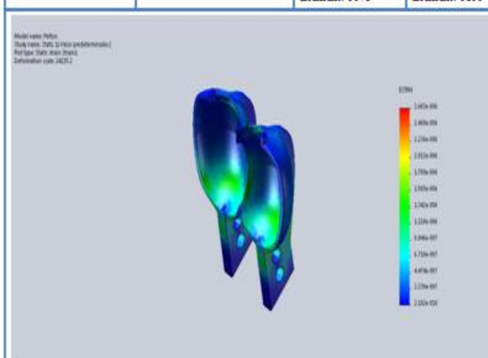
Name	Type	Min	Max
Stress1	VON: von Mises Stress	6.47347e-005 N/mm^2 (MPa) Node: 12075	0.854227 N/mm^2 (MPa) Node: 9737



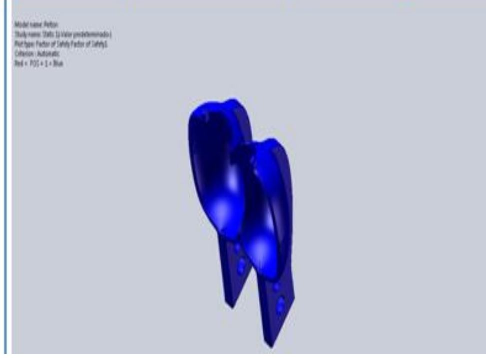
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 499	0.00278099 mm Node: 5427



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.192e-010 Element: 6675	2.68331e-006 Element: 6899



Name	Type	Min	Max
Factor of Safety1	Automatic	411.566 Node: 9737	5.43095e+006 Node: 12075



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International Journal & Magazine of Engineering, Technology, Management and Research
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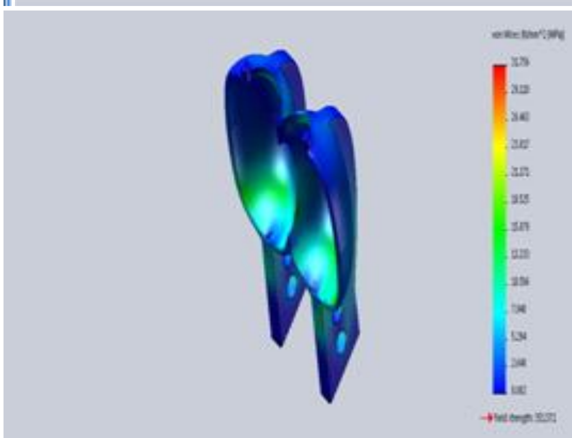
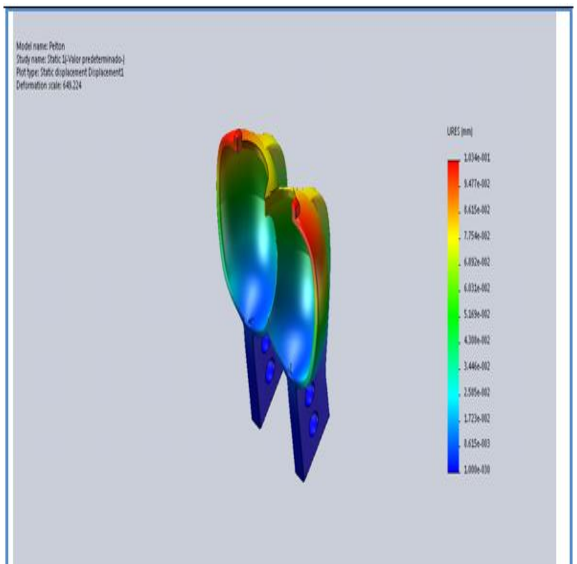
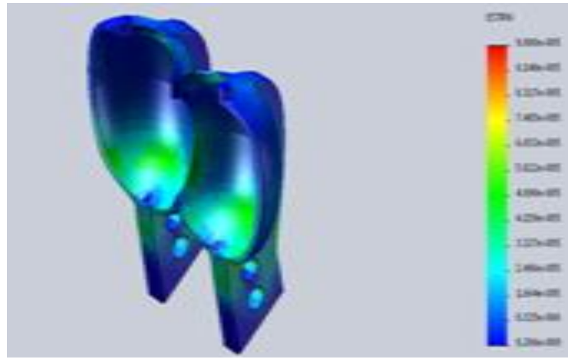
Simulation of traditional bucket using 1020 steel applying 10000 n loads

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.00191046 N/mm^2 (MPa) Node: 12075	31.7556 N/mm^2 (MPa) Node: 9737



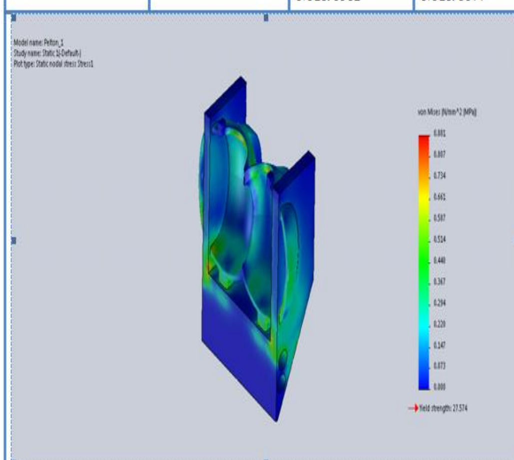


Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	9.28586e-009 Element: 9287	9.97977e-005 Element: 6899



Simulation of advanced or hooped bucket using 1060 alloy applying 269 n load

Name	Type	Min	Max
Stress1	VON: von Mises Stress	4.06447e-005 N/mm^2 (MPa) Node: 8512	0.880773 N/mm^2 (MPa) Node: 8877



Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 258	0.00767573 mm Node: 1624

Simulation of advanced or hooped bucket using 1020 steel applying 269 n loads

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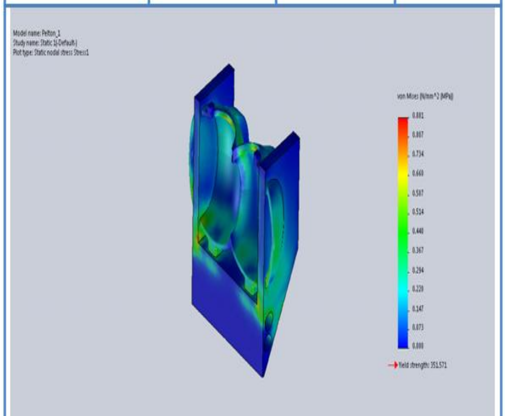
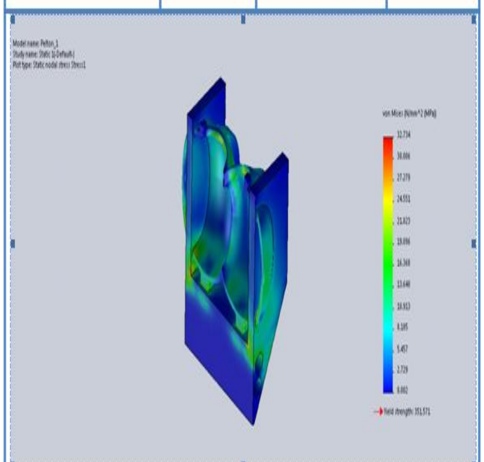
Name	Type	Min	Max
Stress1	VON: von Mises Stress	4.64822e-005 N/mm^2 (MPa) Node: 7907	0.880553 N/mm^2 (MPa) Node: 8877



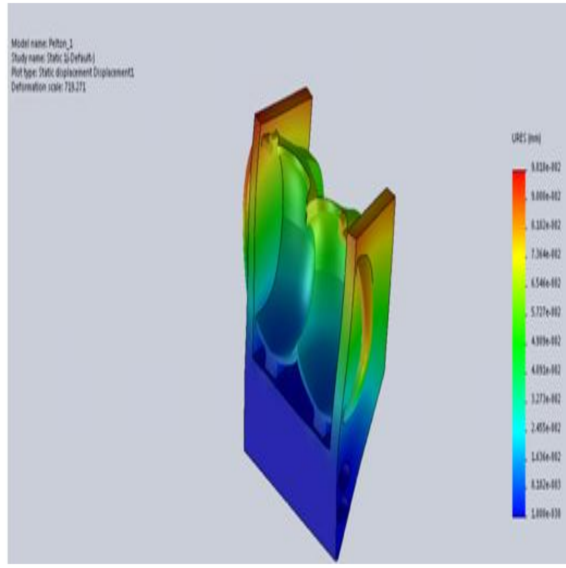
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 258	0.00264115 mm Node: 1624

Simulation of advanced or hooped bucket using 1020 steel applying 10000 n load

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.00172608 N/mm^2 (MPa) Node: 7907	32.7342 N/mm^2 (MPa) Node: 8877



Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 258	0.0981841 mm Node: 1624



RESULTS AND DISCUSSIONS

Advance or hooped runner

The design of the hooped runner is intended to achieve easy maintenance, and the separation of functions facilitates optimization. This runner is composed of two half hoops and buckets.

The definition of the attachment of the various elements to each other is obtained from the stresses transmitted to the various components. The attachment of the buckets is defined based on the centrifugal forces and the jet load. The bucket is modeled as an Inner beam simply supported, resting on its central section and subjected to a force generated by a pre-stressed screw on the outer side. The centrifugal forces are completely taken up by a compound pin (hinge) fixed to the hoops. For the jet force, the Screw load is multiplied by a lever arm effect so as to exert a contact load of the bucket to the rim that is much higher than that of the jet. The stresses transmitted to the hoops are tangential and symmetrical only, the attachment of the hoops to each other is therefore simply a classical assembly using studs. To sum up, buckets are enclosed between two hoops.

By comparing the results obtained from traditional and advanced bucket of pelton wheel we can select the best material under given loading conditions.

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TRADITIONAL	1060 alloy		1020 steel	
	269N	10000N	269 N	10000N
Von misses stresses(Mpa)	0.843608	31.3609	0.85422	31.7556
Displacement (mm)	0.008109	0.30106	0.00278	0.10338
Strain developed	7.89E-006	0.00029E-36	2.68E-006	9.97E-005

ADVANCED	1060 alloy		1020 Steel	
	269N	10000N	269N	10000N
Von misses stresses(Mpa)	0.88077	32.7423	0.88055	32.7342
Displacement (mm)	0.007675	0.2853	0.00264	0.09818
Strain developed	9.582E-8	0.0003E-6235	3.198E-00.6	0.0001E-11

Displacements and stress results prove the validity of the concept. Calculation at synchronous speed shows the participation of the entire hoops to support the water jet forces. This distribution of the water jets forces on the entire hoops involves a decrease of the stress level in the runner. The following figure shows the equivalent stress distribution (VON MISES) in the structural parts of the runner, it means the hoops.

CONCLUSION & FUTURE SCOPE

The development of hooped runner on Pelton wheel during the course of this work leads to the following conclusions. The pelton wheels with traditional bucket have been modeled in a 3D CAD called SOLIDWORKS 2014. The pelton wheel with advanced buket has been modeled in a 3d Cad SOLIDWORKS. Both the traditional and advanced buckets have been simulated in SOLIDWORKS simulation tool, Two different materials such as 1060 alloy and 1020 steel have been applied to traditional and advanced bucket under given loading conditions 269N and 10000N. Even though the von misses' stresses values are almost equal for both traditional and advanced bucket of both the materials. The displacement has been optimal for advanced bucket of pelton wheel. So the best suitable material among the two is 1020 steel.

The analysis carried out in this project is just one step towards optimization. There is large scope of work in this subject. Hoop optimization can be done by parametric study of hoop in which by varying the thickness of hoop it can be achieved. The fatigue analysis of pelton wheel can be done. By conducting experiment Life cycle prediction of pelton wheel is also possible.

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