Design and analysis of Pelton WheelBucket

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***Abstract*— *In this project we have checked newlydevelopdesign 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 isbasedon redistribution of the function of different parts ofpeltonwheel. In conventional runner the jet of water is directlytosplitter of the bucket and transfers the force to it thanbucketsconvert it into momentum by which the shaft is rotateandgiving us power. Whereas in advanced pelton wheelbucketdoes not directly transport the force to the runner buttransfertheforceviathesehoopsandthesehoopsisconnectedtoshaftand by that producing the power so due to hoopedrunnerbucket act as simply supported beam comparing tosimplepelton wheel so stress developed in hooped pelton is lessdueto this construction. In this project we want to achievesomecritical data like stress developed. The project isdirectedtowards the modelling of both traditional andadvancedbucket pelton wheel in a 3D Cad tool calledSOLIDWORKS2014. The both the buckets have been analyzed inSOLIDWORKS simulation tool by using twodifferentmaterials namely 1020 steel and 1060 alloy undergivenloading conditions of 269N and 1000N. Among thebothmaterials the best material is 1020 steel as thestressesdeveloped in 1020 steel is less than the material yieldstrengthunder given loadingcondition.*

***Keywords*—*Peltonwheel,Yield,Stress,Shaft,3DCAD.*

I. INTRODUCTION

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INTRODUCTION

Turbine

A turbine, from the Greek ("turbulence") is arotarymechanical device that extracts energy from a fluid flowandconverts it into useful work. A turbine is a turbo machinewithatleastonemovingpartcalledarotorassembly,whichisashaft or drum with blades attached. Moving fluid acts ontheblades so that they move and impart rotational energy totherotor. Early turbine examples are windmills and water wheels.Gas, steam, and water turbines usually have a casingaroundthe blades that contains and controls the working fluid.Creditfor invention of the steam turbine is given both to theBritishengineer Sir Charles Parsons (1854-1931), for invention ofthereaction turbine to Swedish engineer Gustaf de Laval(1845-1913), for invention of the impulse turbine. Modernsteamturbines frequently employ both reaction and impulse inthesame unit, typically varying the degree of reaction andimpulsefromthebladeroottoitsperiphery.

The word "turbine" was coined in 1822 by the Frenchminingengineer Claude Burdin from the Latin turbo, or vortex, inamemoir, "Desturbineshydrauliquesou machines rotatories a grand evitesse", which he submitted to theAcademieroyaledes sciences in Paris.Benoit Fourneyron, a former studentofClaudeBurdin,builtthefirstpracticalwaterturbine.

Types ofturbines

Steam turbines are used for the generation of electricityinthermalpowerplants,suchasplantsusingcoal,fueloilornuclear power. They were once used to directlydrivemechanical devices such as ships' propellers (for exampletheTurbine, the first turbine-powered steam launch) butmostsuch applications now use reduction gears or anintermediateelectrical step, where the turbine is used to generateelectricity,which then powers an electric motor connected tothemechanical load. Turbo electric ship machinerywasparticularly popular in the period immediately beforeandduring World War II, primarily due to a lack ofsufficientgear-cuttingfacilitiesinUSandUKshipyards.

Classification of hydraulicturbines

The hydraulic turbines are classified according to the typeofenergy available at the inlet of the turbine, direction offlowthrough the vanes, head at the inlet of the turbine andspecificspeed of the turbines. Thus the following are theimportantclassification of theturbine:

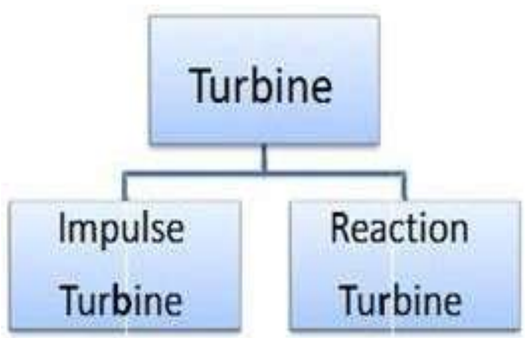


Figure1:Classificationaccordingtoactionoffluidonmovingblades

PENTONWHEEL

The Pelton wheel is an impulse type water turbine. Itwasinvented by Lester Allen Pelton in the 1870s. ThePeltonwheel extracts energy from the impulse of moving water,asopposed to water's dead weight like the traditionalovershotwaterwheel.

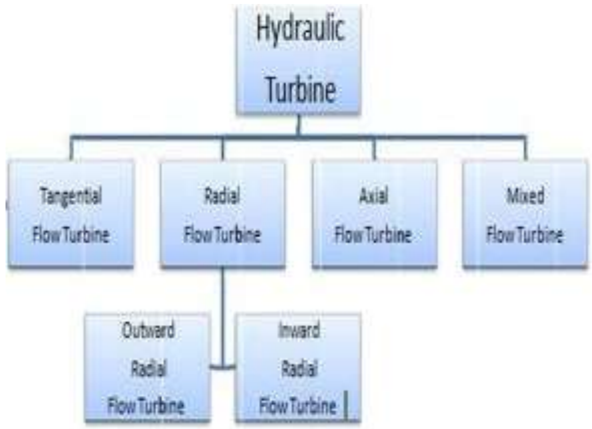


Figure2:Classificationaccordingtodirectionofflowoffluidi n therunner

Many variations of impulse turbines existed prior toPelton'sdesign, but they were less efficient than Pelton's design.Water leaving those wheels typically still had highspeed,carrying away much of the dynamic energy brought tothewheels. Pelton's paddle geometry was designed so thatwhentherimranat½thespeedofthewaterjet,thewaterleftt hewheel with very little speed; thus his design extractedalmostall of the water's impulse energy-which allowed for averyefficientturbine.

Thepeltonturbineoperatingprinciple

The Pelton turbine is an impulse turbine that onlyconvertskinetic every of the flow into mechanical energy. Thetransferof the total energy from the nozzle exit to thedownstreamReservoir occurs at atmospheric pressure. The jetsteamingfrom the injector impinges on buckets, located at theperipheryof awheel.

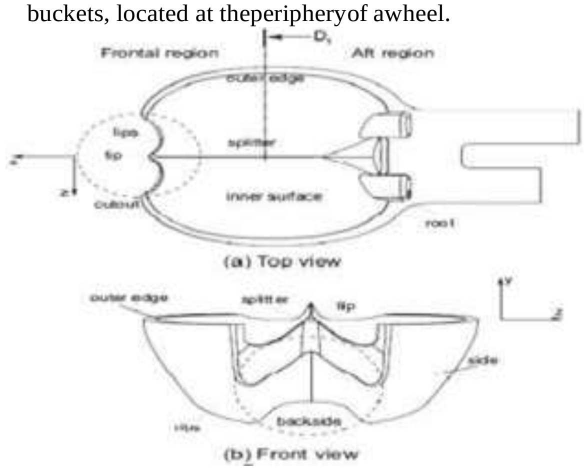


Figure3:BucketsGeometricDefinitio ns

Layout of peltonwheel

The Pelton wheel or Pelton turbine is a tangentialflowimpulse turbine. The water strikes the bucket along the tangent of the runner. The energy available at the inlet oftheturbine is only kinetic energy. The pressure at the inletandoutlet of the turbine is atmosphere. This turbine is usedforhigh heads and is named after L.A. Pelton, anAmericanEngineer. The water from the reservoir flows throughthepenstocks at the outlet of which a nozzle is fitted. Thenozzleincreases the kinetic energy of the water flowing throughthepenstock. At the outlet of the nozzle, the water comes outinthe form of a jet and strikes the buckets (vanes) of therunner.ThemainpartsofthePeltonturbineareNozzleandflo wregulating arrangement (spear), Runner and buckets,Casing,and Breakingjet.

Efficiencies ofturbine

ThefollowingaretheimportantEfficienciesofaturbine.

(A)Hydraulicefficiency(η h)

(B) Mechanical efficiency(η m)

(C) Volumetric efficiency(η v)

(D)Overallefficiency(η o)

Hydraulic efficiency(η h)

Itisdefinedastheratioofthepowergivenbywatertotherunnero faturbine(runnerisarotatingpartofaturbineandon the runner vanes are fixed) to the power supplied bythewater at the inlet of the turbine. The power at the inlet oftheturbineismoreandthispowergoesdecreasingasthewate rflowoverthevanesoftheturbineduetohydrauliclossesasthe vanes are not smooth. Hence the power delivered totherunneroftheturbinewillbelessthanthepoweravailableat the inlet of the turbine. Thus mathematically, thehydraulicefficiencyoftheturbineiswrittenas

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

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

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 turbineistransmitted to the shaft of the turbine. Due to themechanicallosses, the power available at the shaft of the turbine islessthan the power delivered to the runner of a turbine. The ratioof the power available a shaft of the turbine (known as S.P.orB.P.) the power delivered to the runner isdefine asmechanical efficiency. Hence, mat

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

Volumetric efficiency(η v)

The volume of the water striking the runner of a turbineisslightly less than the volume of the water supply to theturbine.Some of the volume of the water is discharged to thetailracewithout striking the runner of the turbine. Thus the ratio ofthevolume of the water actually striking the runner to thevolumeof water supplied to the turbine is defined asvolumetricefficiency. It is writtenas

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

Overall efficiency(η o)

Itisdefineastheratioofpoweravailableattheshaftoftheturbin etothepowersuppliedbythewaterattheinletoftheturbine. It is writtenas

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

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

Forcecalculation

Hereweshownsampleforcecalculationforoneflowrateonly, whole data including readings and results atdifferentflow rate & different opening is given in Appendix-A. thejetof water is comes out from nozzle and strikes on splitter ofthebucket. The force which transferred by jet to the bucketiscalculatedbelow

Flow rate Q =10x10$^{-3m3/sec}$
Runner mean diameter D =360mmHead H= 40m
Speed N= 680rpm

$$V_1 = Kv_1\sqrt{2gh}$$

$$= 0.985\times\sqrt{2\times 9.81\times 40}$$

$$= 27.54 \text{ m/sec}$$

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

Vw1 =v1-u1 = 14.773m/sec
Vw2 = 0.85 x Vw1 = 12.55705m/secVu2 = u2 – Vw2 cos 15 =0.68786m/secSo, Force applied by jet onbucket
Fu= ρ× Q×(Vu1-Vu2)
= (Vu1 – Vu2)
=26.912
Fu = 269N

MODELING OF PELTONWHEEL

Solidworks

Solid Works is mechanical design automation softwarethattakes advantage of the familiar Microsoft Windowsgraphicaluser interface. It is an easy-to-learn tool which makesitpossible for mechanical designers to quickly sketch ideas,experiment with features and dimensions, and producemodels and detaileddrawings.

Introduction to solidworks

Solid works mechanical design automation software isafeature-based, parametric solid modelling design toolwhichadvantage of the easy to learn windows graphicaluserinterface. We can create fully associate 3-D solidmodelswith or without while utilizing automatic or userdefinedrelations to capture design intent. Parameters refertoconstraints whose values determine the shape or geometryofthe model or assembly. Parameters can be eithernumericparameters, such as line lengths or circle diameters,orgeometric parameters, such as tangent, parallel,concentric,horizontal or vertical, etc. Numeric parameters can beassociated with each other through the use ofrelations,whichallowthemtocapturedesignintent.

Layer-cakeapproach

The layer-cake approach builds the part one piece at atime,addingeachlayer,orfeature,ontothepreviousone.

Potter's wheelapproach

The potter's wheel approach builds the part as asinglerevolved feature. As a single sketch representing thecrosssection includes all the information anddimensionsnecessary.

Manufacturingapproach

The manufacturing approach to modelling mimics thewaythe part would be manufactured. For example, if thesteppedshaft was turned a lathe, we would start with a piece ofbarstockandremovematerialusingaseriesofcuts.

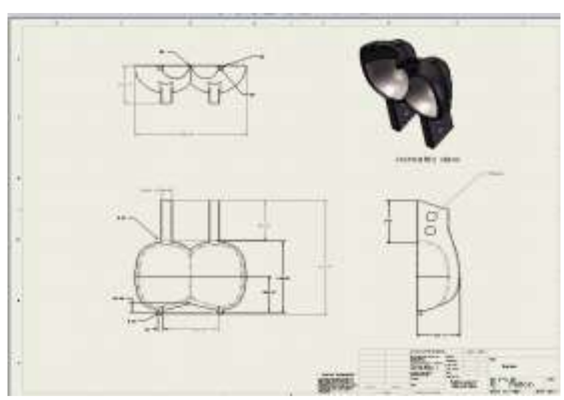


Figure4:dimensionsoftheTraditionalBucket

II. STRESSANALYSISOFSIMPLEANDADVANCED PELTONWHEEL

Thestressanalysesofthetraditionalandhoopedrunnercarried out and compare stress level. Models of traditional andhoopedrunner have same number of buckets and tip diameter whichisused in present numerical simulation, models showing inthischapter.

Modelling

In a traditional runner the bucket is work as a cantileverbeamsubjected to the force generated by the jet. Thesealternatedforces lead to fatigue stresses. Due to the geometry of thebucket,theseatofthesestressesisintheconnectionradius betweentherimandthecentreedgeintheupperpartofthebucket thereby generating traction stresses. In ahoopedrunner the arms are worked as an embedded beam. Bythistype of design decrease stress a t a most failure zone andthetransformation of traction stresses by compression stresses,asthe geometry of the discharge radius is inverted. The hoopisconnectedwithbucketsonarunnerwherebucketsarefitted.

Introductiontosolidworkssimulation:

Solid Works Simulation is a design analysis systemfullyintegrated with SolidWorks. SolidWorks Simulationprovidessimulationsolutionsforlinearandnonlinearstatic,frequency,bucking, thermal, fatigue, pressure vessel, drop test,linearand nonlinear dynamic, and optimization analyses.Poweredby fast and accurate solvers, Solid Works Simulationenablesyou to solve large problems intuitively while youdesign.Soild Works Simulation comes in two bundles:SolidWorksSimulation shortens time to market by saving time andeffortinsearchingfortheoptimumdesign.

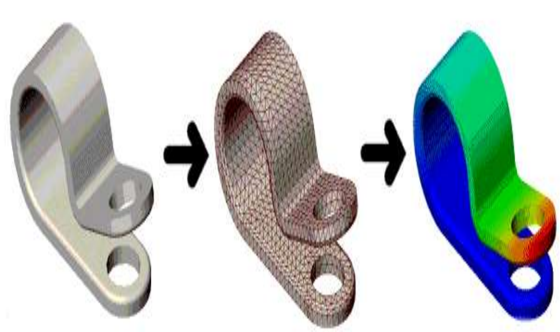


Figure 6: Simulationexample

Benefits ofSimulation:

After building your model, you need to make sure thatitperforms efficiently in the field. In the absence ofanalysistools, this task can only be answered by performingexpensiveandtime-consumingproductdevelopmentcycles.

TotalNodes	19027
TotalElements	10625
Maximum AspectRatio	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
Computername:	SANDEEP-PC

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: Applynormal force; Value: 269 N; Phase Angle: 0; Units: deg

Mesh Information –Details MeshInformation

Meshtype	SolidMesh
MesherUsed:	Standardmesh
AutomaticTransition:	Off
Include Mesh AutoLoops:	Off
Jacobianpoints	4Points
ElementSize	22.6674mm
Tolerance	1.13337mm
MeshQuality	High

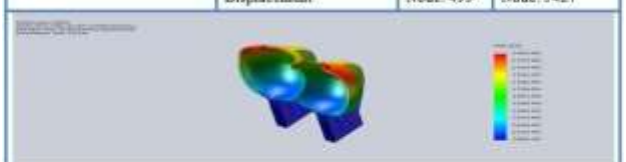
Afactorofsafetylessthan1atalocationindicatesthatthematerial at that location has failed. A factor of safety of 1 atalocationindicatesthatthematerialatthatlocationhasjuststarted to fail. So our design issafe.

Simulationoftraditionalbucketusing1060alloyapplying10000nload

Performing same analysis on bucket by varying loadof10000Ntheresultsobtainedareasfollows

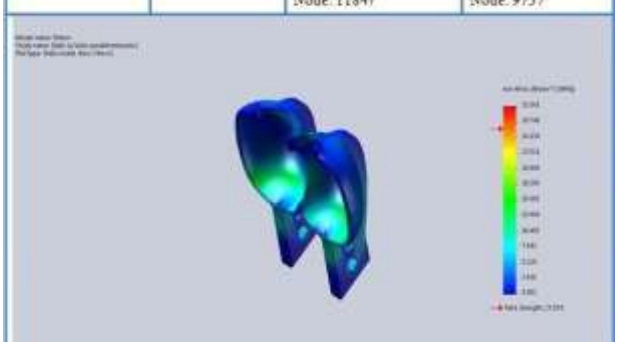
Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.0023459 N/mm^2 (MPa) Node: 11847	31.3609 N/mm^2 (MPa) Node: 9737

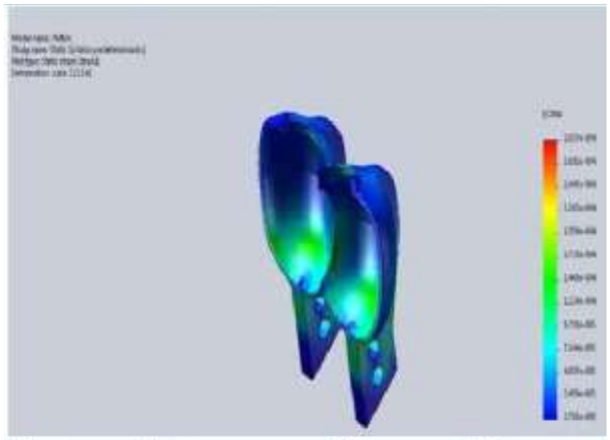
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 499	0.30146 mm Node: 5427



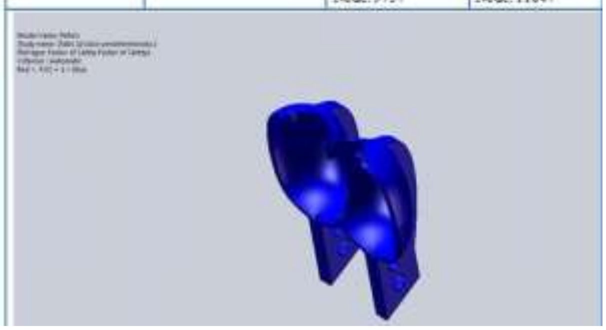
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.78195e-008 Element: 9287	0.000293662 Element: 6899

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



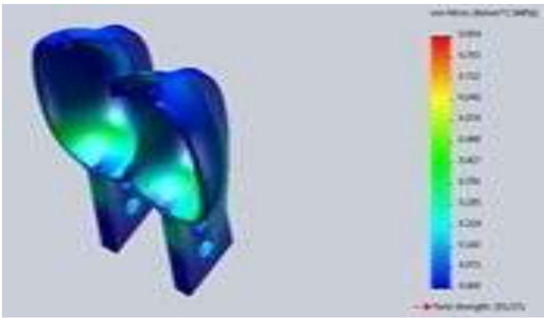
Afactorofsafetylessthan1atalocationindicatesthatthematerial at that location has failed. A factor of safety of 1 atalocationindicatesthatthematerialatthatlocationhasjuststartedtofail.Afactorofsafetygreaterthan1atalocationindicates that the material at that location is safe. Sooordesign is not safe. Simulation of traditional bucket using1020steel applying 269n load: Performing same analysis onbucketbyvaryingloadof10000Ntheresultsobtainedareasfollows

MaterialProperties

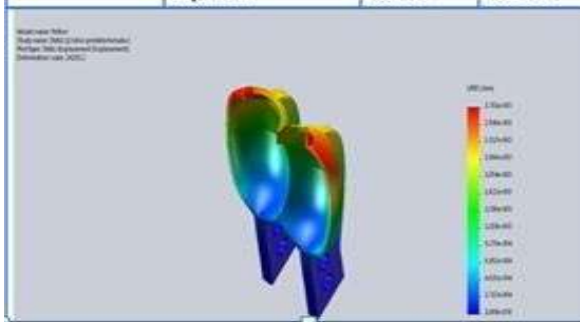
Material Properties

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	

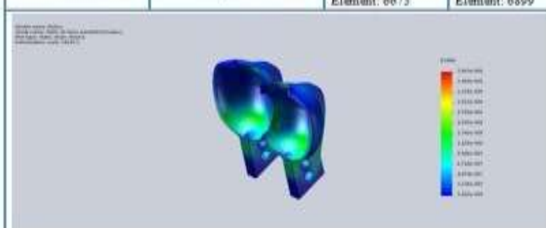
Name	Type	Min	Max
Stress1	VON: von Mises Stress	6.47347e-005 N/mm^2 (MPa) Node: 12075	0.854227 N/mm^2 (MPa) Node: 9737



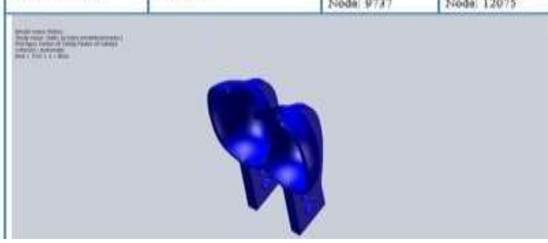
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 499	0.00278099 mm Node: 5427



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

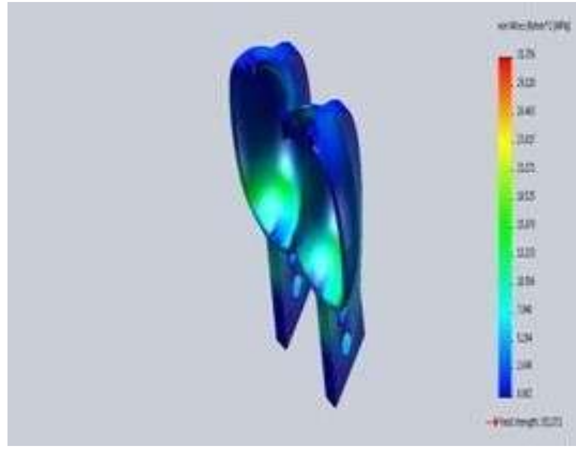


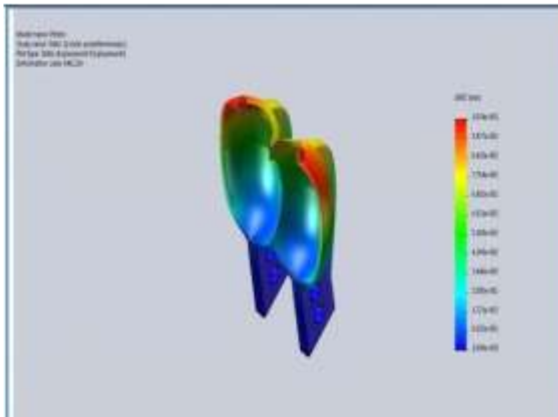
Name	Type	Min	Max
Factor of Safety1	Automatic	411.366 Node: 9737	5.43095e+006 Node: 12075



Simulation of traditional bucket using 1020 steelapplying10000 nloads

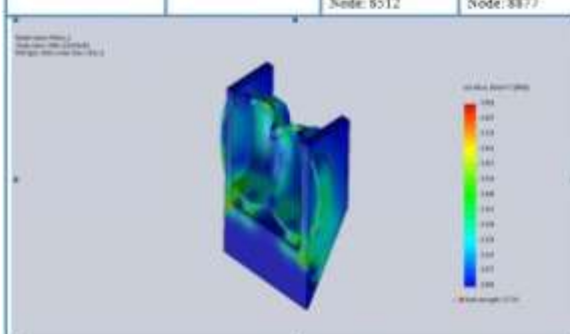
Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.00191046 N/mm^2 (MPa) Node: 12075	31.7556 N/mm^2 (MPa) Node: 9737





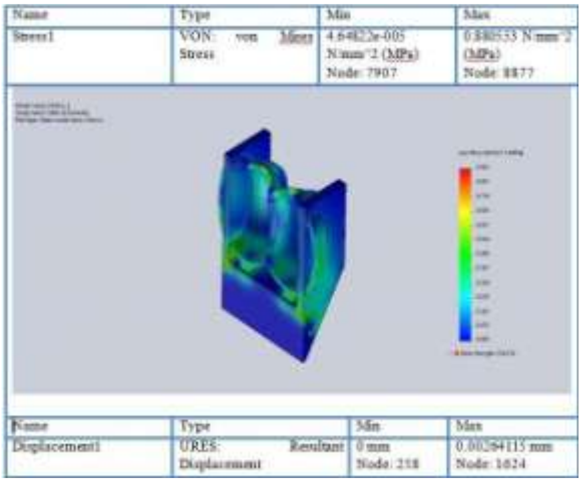
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	9.28586e-009 Element: 9287	9.97977e-005 Element: 6899

Name	Type	Min	Max
Stress1	VON: von Mises Stress	4.08447e-005 N/mm^2 (MPa) Node: 8512	0.880773 N/mm^2 (MPa) Node: 8877

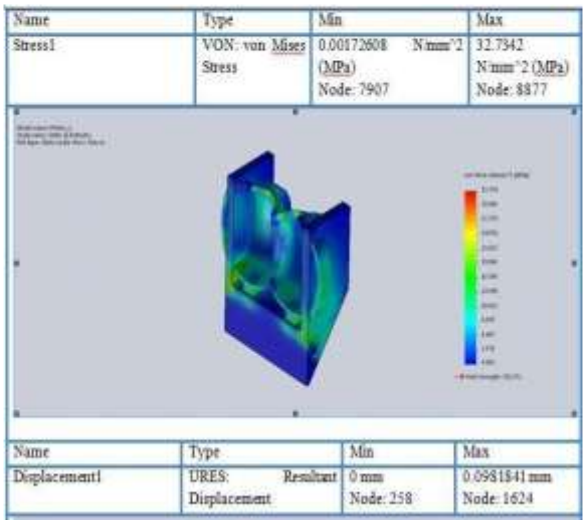


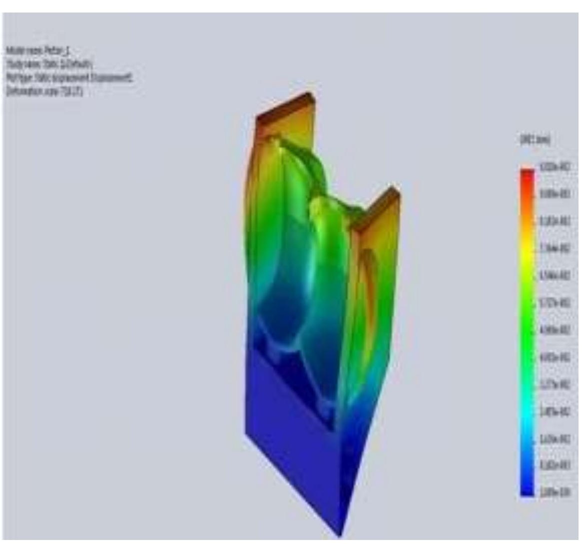
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 258	0.00767575 mm Node: 1624

Simulationofadvancedorhoopedbucketusing1020steelapplying 269 nloads



Simulation of advanced orhooped bucket using1020steelapplying 10000nload





RESULTS AND DISCUSSION Advance or hoopedrunner

The design of the hooped runner is intended to achieve easy maintenance, and the separation of functionsfacilitatesoptimization. This runner is composed of two half hoopsandbuckets. The definition of the attachment of thevariouselements to each other is obtained from thestressestransmitted to the various components. The attachment ofthebuckets is defined based on the centrifugal forces and thejetload. The bucket is modelled as an Inner beamsimplysupported, resting on its central section and subjected toaforce generated by prestressed screw on the outer side.Thecentrifugal forces are completely taken up by a compoundpin(hinge) fixed to the hoops. For the jet force, the Screw loadismultiplied by a lever arm effect so as to exert a contact loadof the bucket to the rim that is much higher than that of thejet.The stresses transmitted to the hoops are tangentialandsymmetrical only, the attachment of the hoops to each otheristherefore simply a classical assembly using studs. To sumup,buckets are enclosed between twohoops.

By comparing the results obtained from traditionalandadvanced bucket of pelton wheel we can select thebestmaterialundergivenloadingconditions.

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	1060alloy		1020Steel	
	269N	10000N	269N	10000N
Vonmisses stress(Mpa))	0.88077	32.7423	0.88055	32.7342
Displacement (mm)	0.007675	0.2853	0.00264	0.09818
Straindeveloped	9.582E-8	0.0003E-	3.198E-	0.0001E-

Displacement and stress results prove the validity oftheconcept. Calculation at synchronous speed shows theparticipationoftheentirehoopstosupportthewaterjetforces.This distribution of the water jets forces on the entirehoopsinvolves a decrease of the stress level in the runner.The following figure shows the equivalent stressdistribution(VON MISES) in the structural parts of the runner, it meansthehoops.

IV. CONCLUSION

The development of hooped runner on Pelton wheelduringthe course of this work leads to the followingconclusions.The pelton wheels with traditional bucket have beenmodeledin a 3D CAD called SOLIDWORKS 2014. The peltonwheelwith advanced buket has been modeled in a 3dCadSOLIDWORKS. Both the traditional and advancedbucketshave been simulated in SOLIDWORKS simulation tool,Twodifferent materials such as 1060 alloy and 1020 steelhavebeen applied to traditional and advanced bucket undergivenloading conditions 269N and 10000N. Even though thevonmisses'stressesvaluesarealmostequalforbothtraditionaland advanced bucket of both the materials. Thedisplacementhas been optimal for advanced bucket of pelton wheel. Sothebest suitable material among the two is 1020 steel.Theanalysis carried out in this project is just one steptowardsoptimization. There is large scope of work in thissubject.Hoopoptimizationcanbedonebyparametricstudyofhoopinwhichbyvaryingthethicknessofhoopitcanbeachieved.The fatigue analysis of pelton wheel can be done.Byconducting experiment Life cycle prediction of pelton wheelis alsopossible.

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