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Design and Analysis of cross flow impulse turbine for water stream near Trapi village KPK Pakistan.

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Abstract

Pakistan is investing handsome amount in favor of setting up and evaluating the hydropower and hydro potential sites in Pakistan. This study is useful in calculating different selected turbine related parameters, their mutual relations and constraints effected by flow rate and head. The project can be beneficial and may be used as a reference for fabrication of a cross flow impulse turbine for energy generation on small scale.

Keywords: Head, Flow rate, Analyses, modeling.

1. Introduction

This article is about our work oriented to design and analysis of cross flow water turbine from the rural site of a seasonal spring at Trapi village situated about 160 km(s) from the capital Islamabad, Pakistan. Such turbine are applicable where there is very low head and flow rates are available. This turbine is also used for domestic purposes where there is no supply of electricity epically in mountain region i.e. remote areas. We have edge over fabrication of turbine due to simple geometry and it is performance is not too much dimensions sensitive. The article is based on designing an impulse water turbine and its feasibility. The core work of this project is based on design, model and analyses of cross flow Impulse water turbine. This article intends to explore and optimize energy generation the hydro potential sits of Pakistan to contribute countering the energy crises of the state

1.1 Cross flow Turbine: The Cross flow turbine comprises of a rotor like wise to a drum with a solid disk at each end and joining the two side disks [1]. A jet of water enters with a certain velocity the top of the rotor glides through the curved blades, flushes out on from far bottom end of the rotor by passing through the blades. The shape of the blades is fabricated in such a way that on each passage between the periphery of the rotor the Water transfers some of its momentum and force, before falling away with little residual energy [2].

1.1.1 Runner: Runner blades are manufactured from pipe sections and these are also fabricated or milled. Blades are connected by two discs called side discs on the shaft. If mass of turbine exceeds, bracing is sublimated to discs if required depending on the stress conditions and calculations. The shaft runs through the runner as one piece. The optimal running speed of the turbine is depends on the optimal running speed of the generator. If generator speed is estimated to be 1500 rpm the turbine is to be drags to have an optimal running speed up to at least 750 rpm [3]. The running speed may be increased by reducing the runner turbine diameter or increasing the head if available. Decreasing the diameter will increase the complexity of manufacture and cost so the running speed may be kept slightly less than 750 rpm [3].

1.1.2 Draft Tube: The draft tube is key module for manipulating the difference between runner and downstream water level. During the turbine Operation the air cavitation in the casing is injected in flushed out along with the water. Thus a vacuum is formed. With respect to exterior atmospheric pressure there is increment in suction column. And to counter this a provision is mounted which is a simple venting valve which is free of friction and the sole purpose of it controls the vacuum in the turbine casing to stabilize the energy potential.

1.1.3 Nozzle: The nozzle is the component with rectangular cross section area, discharges the water which impinges entire width of the turbine and usually enters the wheel at an angle of 16^o w.r.t. tangential direction of the periphery of the rotating drum. The rectangular shaped jet is wide, and not too much deep. The water impinges on the blades mounted on the rim of the wheel, flows and glide over the turbine blade and leaves it, passing through the empty space between the middle parts of rim, enters the blade at lower side inner side of the rim, and discharges from the outer rim periphery. A variable area of nozzle is required for the alteration of jet thickness. That is the reason the optimal jet thickness could not be determined without experiment. This shall be done with a variable guide vane which has person to be locked into place with a basic ratchet system.

Characteristics of Cross Flow Turbines [4]:

- Cross flow runners have a definite operating 'range' transitionally between Propeller and Pelton of turbine types.
- Running at speeds calculated by the head they are operating (between 300 to 1500rpm).
- The head at which the cross flows is the best choice (with manageable operating speeds of between 500 to 1,000rpm)
- The turbine uses the head about 5-6 meters at minimum power (1-10kW) but up to 100 meters head can be suitable for higher powers up to 500 kW.
- This turbine have a speed as low as 300rpm for a runner operating at a low head and as high as 1,500rpm for medium range and small runner operating at high head.

2. Technical Terminology:

Some technical terminologies which are use are as follows [5]:

Pitch circle Diameter of runner= Dp

Outer Diameter of Runner = Do

Root Circle Diameter of Runner = Dr

Shaft diameter of Runner = d

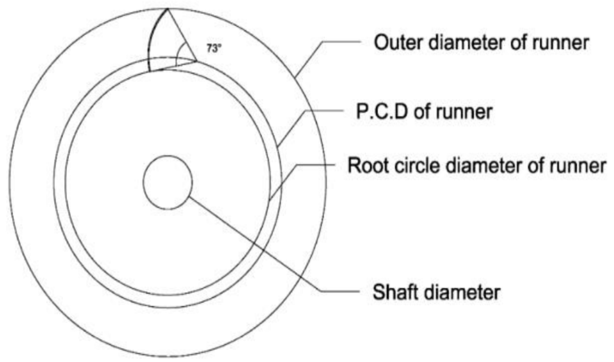


Figure 1 Parts of turbine runner [2].

Pitch circle Diameter of runner [6] The diameter of turbine runner from which the radius or curvature of blade is drawn.

Outer Diameter of Runner [6] It specifies that diameter of Runner at which turbine Blade intersects the side metal plates on the inner rim.

Root Circle Diameter of Runner: It is the Maximum Diameter of Turbine Runner, at which the Blade intersects the side Plate at the outermost edge [6].

Shaft diameter of Runner: The Shaft passes through the runner. The Diameter of Shaft depends upon the maximum or outer diameter of the turbine runner [6].

The velocity triangle: The blades of turbine under goes from the following forces and fluid shows the following velocity behavior. All paths are shown diagrammatically forming triangles known as velocity triangles.

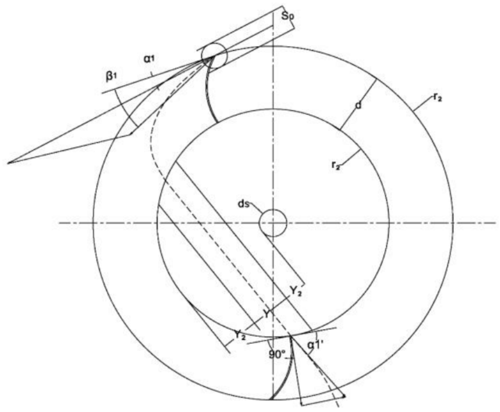
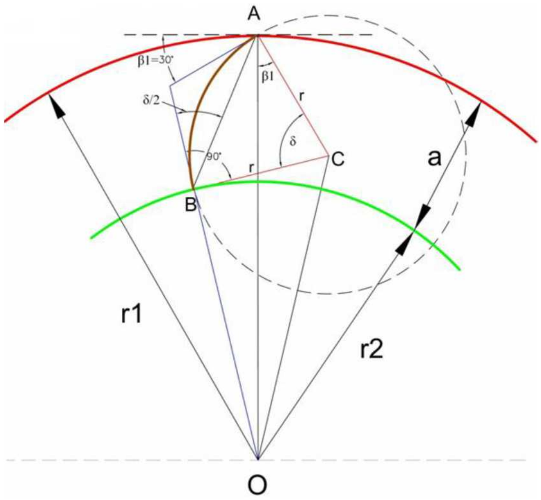


Figure 2 Velocity Diagram for Cross Flow Turbine [7]

Cross flow blade profile:

The curve of the blade must be chosen from a circle whose center lies at the intersection of two perpendiculars, to the direction of relative velocity at and the other to the tangent to the inner periphery intersecting at.



Formulas used:

The calculation starts first by calculating net head. Other formulas used for carrying out various turbine parameters are following afterward:

A. Calculation of the net head:

This includes the calculations and measuring the net head of the hydro-power plant and its water flow rate [8].

Hn = Hg – Htl (m)

Where Hg = the gross head which was the vertical distance between water surface level at the intake and at the turbine. Htl = total head losses due to the open channel, trash rack, intake, penstock and gate or value. These considered losses equivalent to 6% of gross head.

B. Calculation of the water flow rate (Q):

The water flow rate can be calculated by measuring river or stream flow velocity (Vr) and river cross-sectional area (Ar), then:

Q = Vr x Ar (m^3/s)

C. Relation of power produced by Turbine (Pt):

In terms of wattage the electrical can be calculated as:

$P_t = \rho * g * \eta_t * H_n * Q$

D. Relation for turbine efficiency (η_t):

The maximum turbine efficiency can be calculated as:

$\eta = 12 \times C2 \times (1+\psi) \times cos2\alpha$

E. Relation for the turbine speed (N):

The Turbine speed can be calculated with the formula below:

$N = 513.25 \times Hn0.745\sqrt{Pt}$ (r.p.m)

F. Calculation of runner outer diameter (Do):

The outer diameter of runner can be calculated using the following formula:

$D_o = 40 \times HnN$ (m)

G. Calculation of blade spacing (tb):

The tangential blade spacing can be calculated using the below formulae

tb = 0.147× Do

The tangential spacing (tb) is given as:

$t_b = tesin\beta1 = K \times Dosin\beta1$

Where β1 = blade inlet angle = 30° when α = 16°.

H. Calculation of the radial rim width (a):

It is the difference between the outer radius (ro) and inner radius (ri) of the turbine runner, so it is equal to the blade spacing and can be given as:

A = 0.174×Do (m)

I. Relation for the runner blade number calculation (n):

The number of the runner blades can be determined as

$n = \pi \times Dotb$

J. relation for calculating water jet thickness (tj):

It is also defined as nozzle width and can be calculated as

$tj = 0.233 \times QL \times \sqrt{Hn}$ (

K. Relation to determine Runner Length (L):

The runner length in meters can be calculated as:

$L = Q \times N50 \times \sqrt{Hn}$ (m)

Calculation of the distance between the water jet and the center of the runner (Y_1):

$Y1 = 0.116 \times Do$

L. Calculation of the distance between water jet and the inner periphery of runner (Y_2) [9]:

$Y2 = 0.05 \times Do$

M. Calculation of inner diameter of runner (Di):

$Di = Do - 2\times a$

N. Calculation of blade radius of curvature (r_c):

$r_c = 0.163 \times Do$

O. Calculation of blade inlet angle (β1):

$\tan\beta1 = 2\times \tan\alpha$

P. Calculation of the blade exit angle (β2):

The blade exit angle should be of $\beta2 = 90^\circ$

Q. Calculation of Diameter of shaft (d_{shaft}):

The shaft diameter can be calculated by the formula as under.

$d_{shaft} = 0.22 \times Do$

R. Calculation of Absolute Velocity of water (V1):

The absolute velocity can be calculated by the formula as follows.

$V_1 = c\sqrt{2gH_n}$

Where "C" is the roughness coefficient of nozzle.

Site perimeters and constants values:

S.no.	Perimeter	Symbolic Representation	Quantity	Units (S.I.)
1	Net Head	Hn	9	Meter(s)
2	Flow rate	Q	1.3	m3/sec

Constant Values:

S.no.	Perimeter	Symbolic Representation	Constant quantity Quantity
1	Blade roughness coefficient	ψ	0.98(unitless quantity)
2	Nozzle roughness coefficient	C	0.98(unitless quantity)

Derived values of turbine from reference site values using formulae:

S.no.	Perimeter	Symbolic Representation	Quantity	Units (S.I.)
1	Turbine power	Pt	100.47	watts
2	Efficiency	ηt	87.8	percentage
3	Turbine speed	N	263.15	R.P.M.
4	Specific turbine speed	Ns	32.92	R.P.M.
5	Runner outer diameter	Do	0.45	meters
6	Blade spacing	tb	0.0783	meters
7	Thickness of jet entrance	te	0.03915	meters
8	Radial rim width	a	0.783	meters
9	Number of blades	n	18	meters
10	Water jet thickness	tj	0.1305	meters
11	Runner length	L	0.76	meters
12	Distance b/w water jet and shaft center	Y1	0.0522	meters
13	Distance b/w water jet & periphery of runner	Y2	0.0225	meters
14	Inner diameter of runner	Di	0.2934	meters
15	Radius of curvature of blade	ri	0.07335	meters
16	Water inlet angle	B1	30˚	degrees

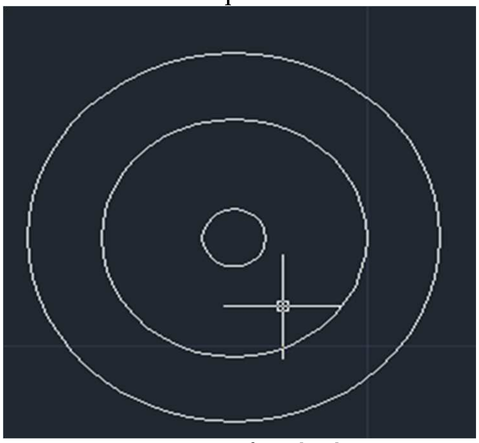
17	**Water exit angle**	**B2**	**90˚**	**degrees**
18	**Angle of attack**	**α**	**16˚**	**degrees**
19	**Diameter of runner shaft**	**dshft**	**0.099**	**meters**
20	**Absolute velocity of water**	**V1**	**13.02**	**cubic meter/sec**
21	**Centre angle of Blade**	**δ**	**73˚52'7.06"**	**Degrees/minuts/ seconds**

Modeling of Cross flow Turbine

The software used for modeling is Autodesk AutoCAD which is drafting and modeling computer application. The version used here is Autodesk AutoCAD 2012.

Starting from the scratch

The modeling is simple first I have created a 2d profile of turbine pictorially demonstrated below. Runner outer and inner periphery circles and middle circle equivalent to shaft diameter.



Figurer-3 Start of 2D sketching

Blade Profiling:

Formation of Blade with the help of angles derived through previously mentioned formulas

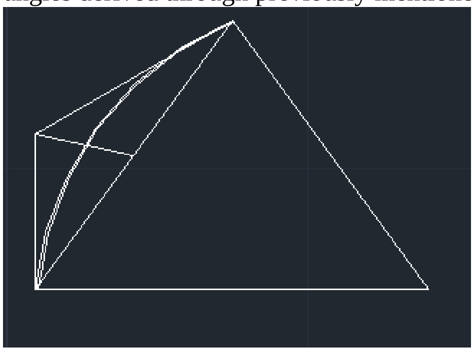


Figure -4 Drafting of blade profile

Blade Profile insertion in runner profile:

The blade profile is inserted in the runner profile with the help of move command

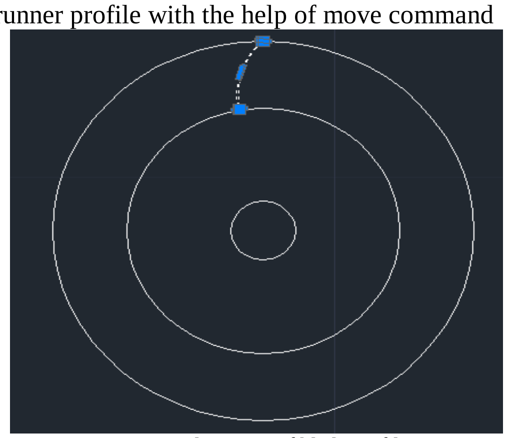


Figure -5 Placement of blade profile.

Blade array generation on runner periphery:

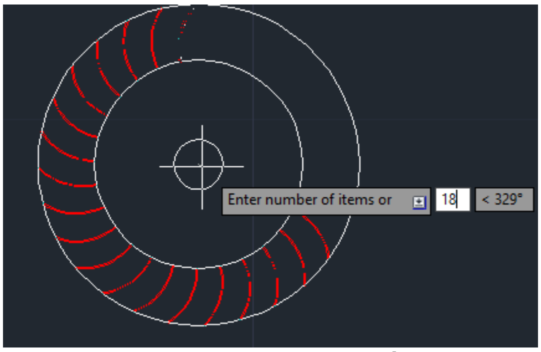


Figure-6 Usin array command.

Extruding and export:

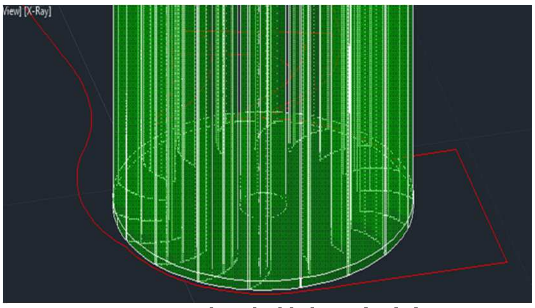


Figure-7 Extruding the blades and sidediscs.

Extruded, trimmed, moved and thicken command are used and transformed the 2d image to 3d and finalize the modeling. The finished model is exported in IGES format to in order to import it to analyses software.

Casing Modeling:

Casing modeling is done in the same way as the runner.

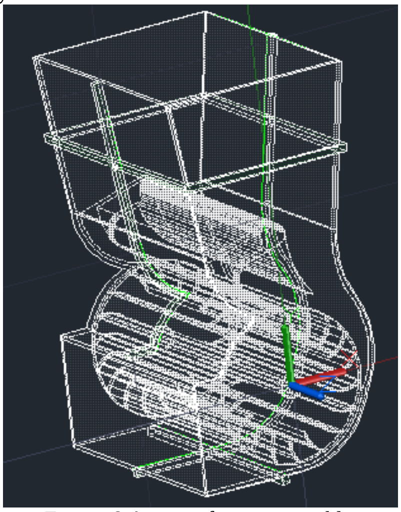


Figure -8 A view of entire assembly.

Analyses of cross flow turbine

Import

The software package used here is ansys 16.1 version. The IGES generated by AutoCAD is imported in Ansys.

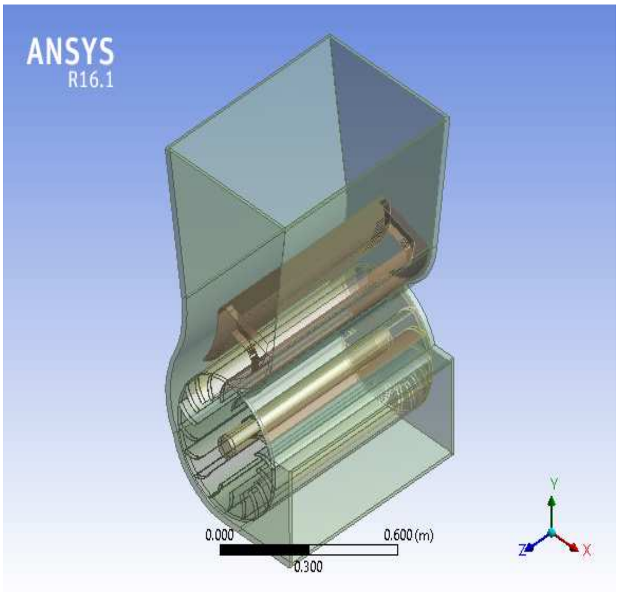


Figure -9 Import of geometry using IGES

Casing Stress Analyses

Material Selection:

Steel is used as the material for casing and turbine

Meshing

The mesh is generated in the ANSYS workbench mesh module. Unstructured mesh with tetrahedral elements is created. Total number of elements created are 236255.

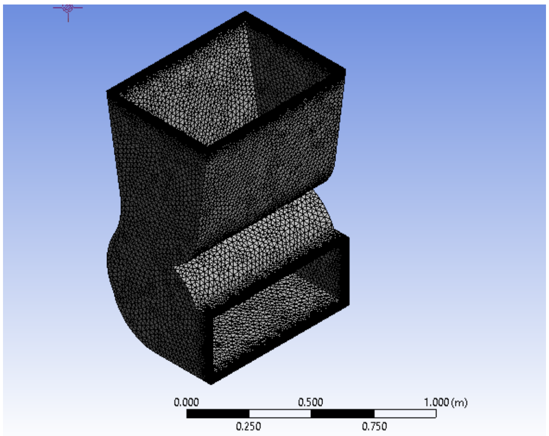


Figure -10 Mesh view of turbine casing

Details of "Mesh"

Physics Preference	Mechanical
Relevance	0
Sizing	
Inflation	
Patch Conforming Options	
Patch Independent Options	
Advanced	
Defeaturing	
Statistics	
Nodes	396302
Elements	236225
Mesh Metric	None

Figure -11 Total nodes and elements.

Boundary Conditions:

Pressure

P = ρgh

Where p is the pressure, ρ is the density, g is the gravitational constant with value = 9.81 m/sec^2. h is the height of the water column above the turbine.
Using the following values for our calculations
ρ= 1000 kg/m^3
g= 9.81 m/s^2
h= 9 m
The pressure comes out to be = 8.86 e 4 pa
Constraint Boundary condition:
The turbine casing is constrained by applying fixed supports at the top and bottom ends as shown below

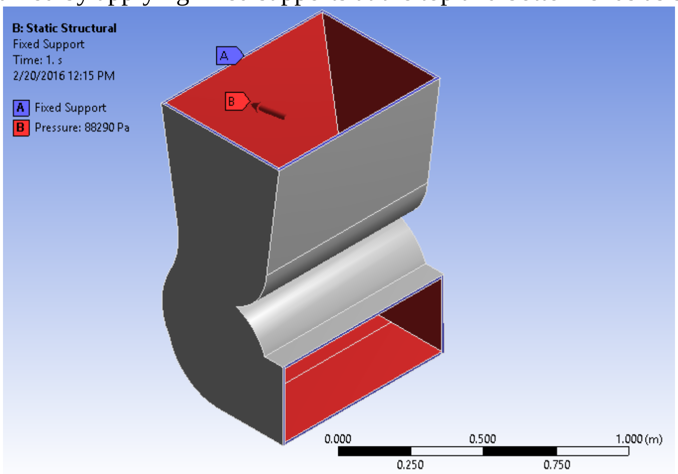


Figure - 12 Supported and pressure applied surfaces.

Results:
The stress analysis of the casing gave the results pressure in Figure above Von mises stress failure criteria is used which is presented below.
The deformation, stress, strain and factor of safety contours are presented below.
The maximum deformation is seen to be in the middle of upper part of casing and is equal to 0.82mm. Stress induced due to applied pressure in the casing is approx. = 98.9 Mpa and is present near the top fixed constrained condition. The corresponding strain induced due to applied pressure in the casing is approx. = 0.000585 Nm/m and is also present near the top fixed constrained condition.

Factor of safety => $n = \frac{\text{yield stress}}{\text{Stress induced due to loading}}$

Yield stress = 250 Mpa
Stress induced in the casing due to loading = 98.9

$n = \frac{250}{98.9} = 2.527$

The factor of safety shows that our casing under the applied loading is safe and is below the failure limit. However, In order to further reduce the deformation, stress and strain we can reinforce our casing by applying ribs in the center of the upper part of casing as shown in the figure

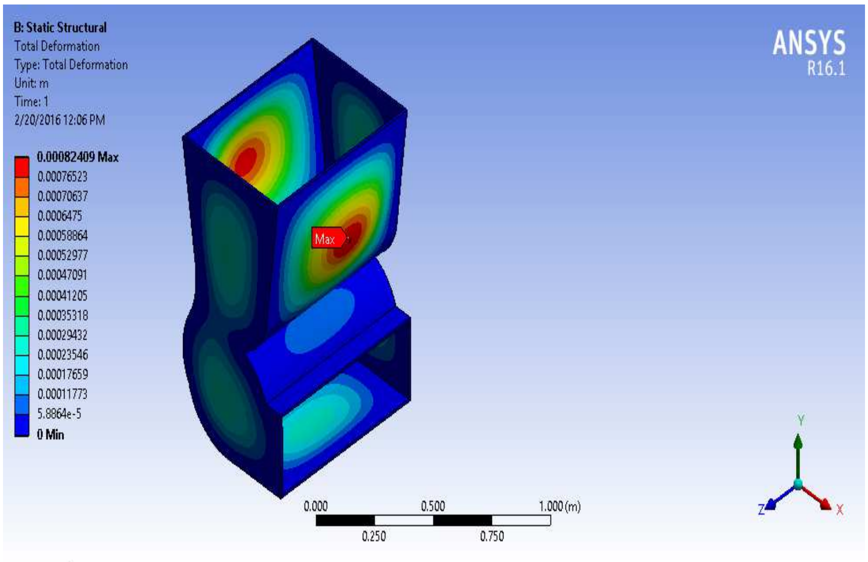


Figure -13 Casing total Deformation.

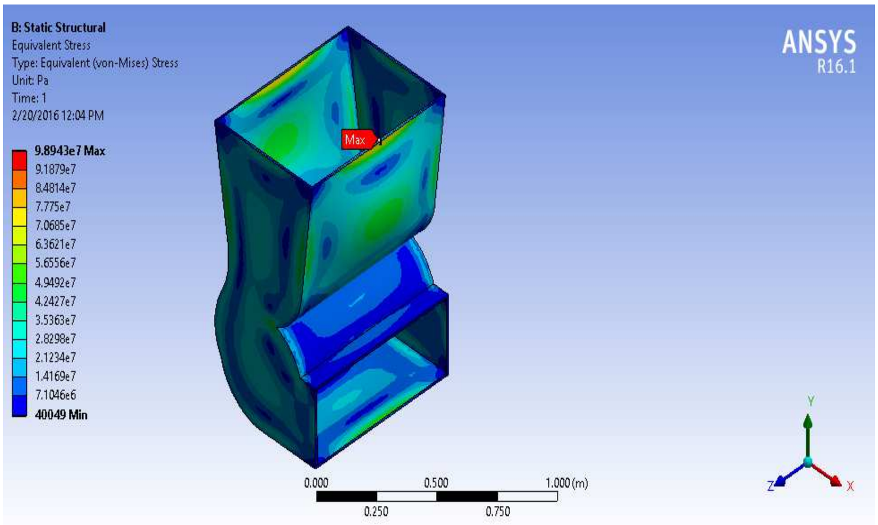


Figure -14 Casing equivalent Stress.

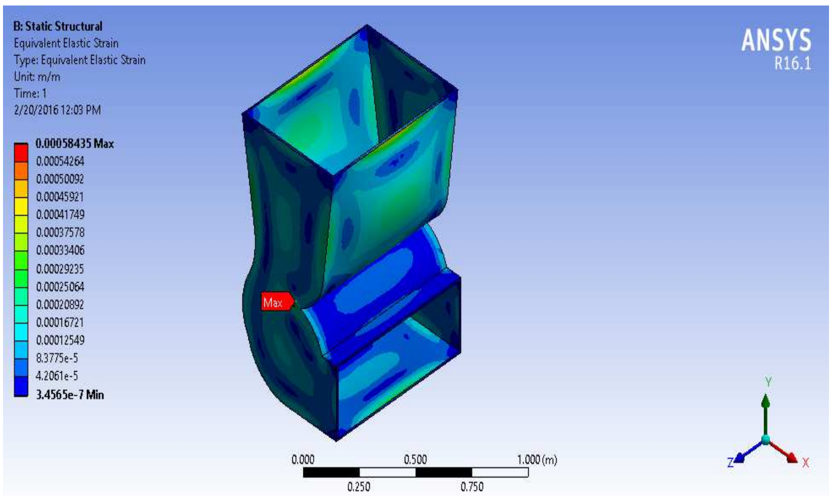


Figure -15 Casing equivalent elastic strain.

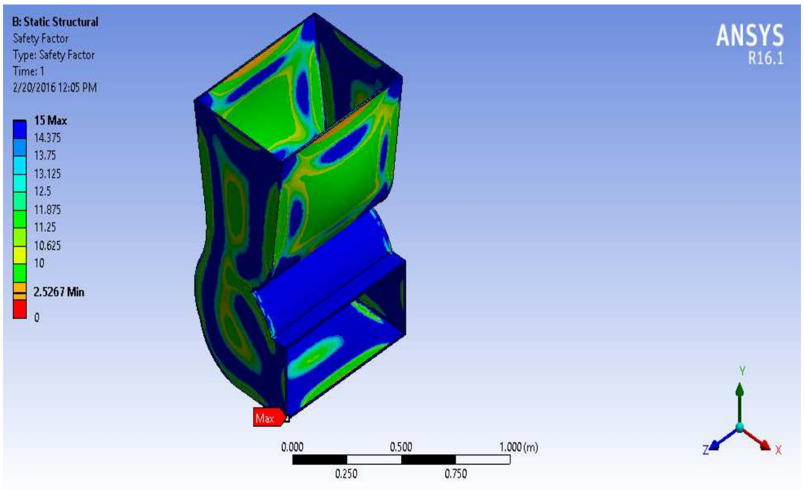


Figure -16 Casing factor of safety.

Runner Stress Analyses

Geometry Import:

Below is the view of imported geometry of runner from AutoCAD.

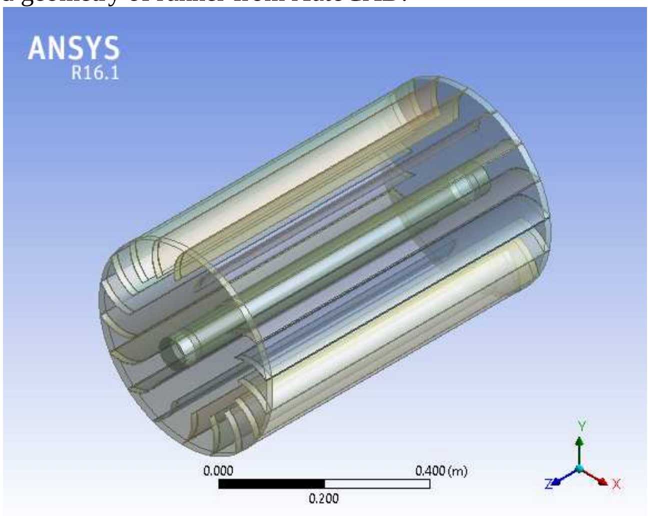


Figure **Error! No text of specified style in document.**-37 Runner IGES import.

Results: The runner has eighteen blades equidistant mounted on the side discs. The assigned fixed supports are the interfacing areas between the shaft and side disc. The shaft is suppressed from analyses due to computing power issues.

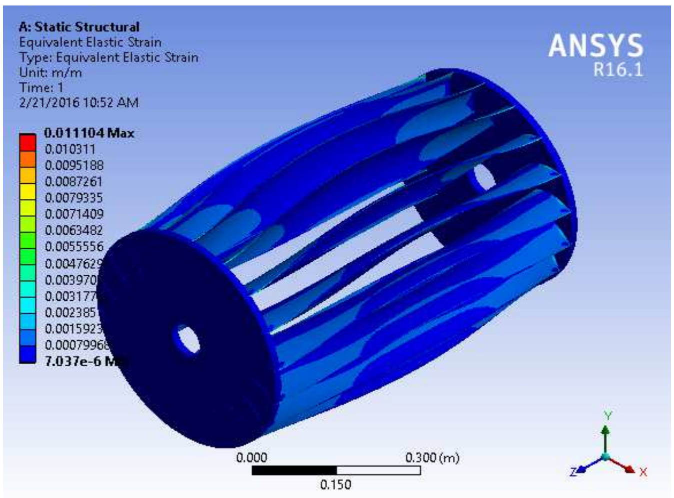


Figure -18 Turbine equivalent stress

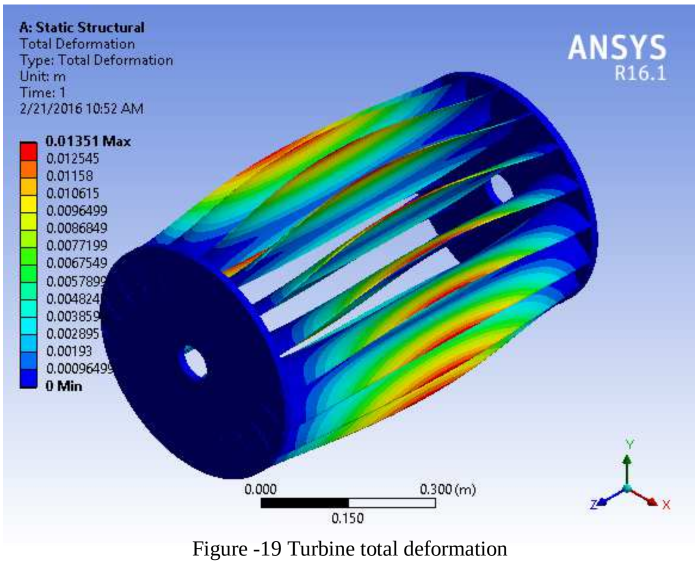


Figure -19 Turbine total deformation

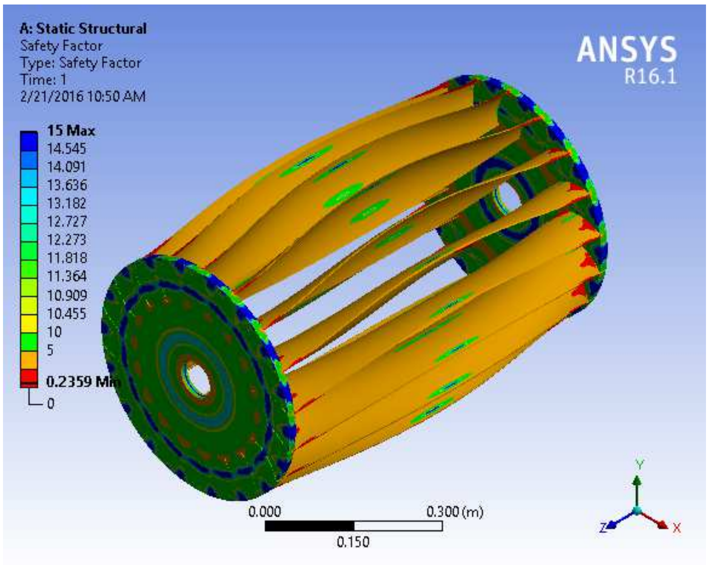


Figure -20 FOS for runner

Conclusion:

Pakistan is investing the hand some amount in favor of exploration and installation of hydropower plants. Our objective (proposal problem statement) was to design and analyses the turbine for the hydro potential sit and its feasibility study. We take a site (seasonal stream) at the location named Trappi which is about 155 kilometers from capital Islamabad in KPK province. The turbine can be designed as per the perimeters the head and flow rate available on site. The turbine can be operated at very low head and flow rate. It can also installed on domestic level also. The turbine is ideal for the home cottage industry especially in current power crises of the country. One of the novel idea is to build a small reservoir of water in which water is collected all day and during night by running the power plant we power up the street lamps of nearby highway in peak hours(for e.g. motorway interchange, road crossing traffic signals etc.)

We designed the turbine, analyzed it and we can also fabricate it locally. It seems a little mile stone but through implementation of further more number of these projects we cope with the energy crises. The most important fact is that the hydro power is the cheapest of all other resources and fossil fuels should kept secondary option because of huge cost and to reduce environmental hazards (Ozone depletion, greenhouse effect and pollution).

We have also fitted the casing with rib supports by which we counter deformation and drag the factor of safety further towards the safe side.

Cross flow turbine power plants are much feasible because Pakistan has countless sits especially in the Pohotwar platue region, Baluchistan and KPK areas due to the presence of glaciers in northern areas, which melts during the summer and at lower stream (Pohotwar platue, Baluchistan and KPK areas) if these plants are installed contributes a lot in power short falls of state.

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