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Design and Analysis of Low Head, Light weight Kaplan Turbine Blade

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ABSTRACT:- The project deals with the development of the design of low head light weight Kaplan turbine blade. To enhance it's hydrodynamic efficiency by reducing weight, shape alterations, blade angle with combination of materials Aluminium alloy, Structural steel, Titanium alloy Stainless steel. The 3D model of blade is developed using software Solid Works and Analysis of blade is done on Ansys14..
Keywords:- Development, design, low head, light weight, Kaplan Turbine.

I. INTRODUCTION

A turbine 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. Gas, steam and turbines have a casing around the blades that contains and controls the working fluid.

The Kaplan turbine is an outward or inward flow reaction turbine. Here working fluid changes pressure as it moves through the turbine. Power is gained from both the hydrostatic head and from the kinetic energy of flowing water. The Kaplan turbine is an outward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. Power is recovered from both the hydrostatic head and from the kinetic energy of the flowing water. The design combines features of radial and axial turbines.

1.1 Components of Kaplan turbine

Scroll casing: casing in which water passes to the runner in the turbine. The water from the penstocks enters the scroll casing and then moves to the guide vanes.
Guide vanes: these guide the water and control the water passage. The Guide Vanes are fixed on the Hub.
Draft tube: After passing through the runner, the water is discharged to the tail race through a gradually expanding tube called draft tube.
Runner: it is connected to the shaft of the generator and consist movable vanes and hub (boss).
Hub (Boss):- It is the part of runner on which blades are mounted.

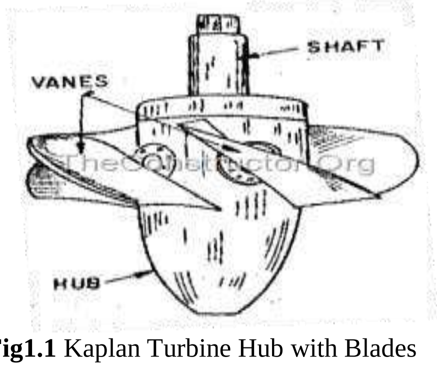


Fig1.1 Kaplan Turbine Hub with Blades

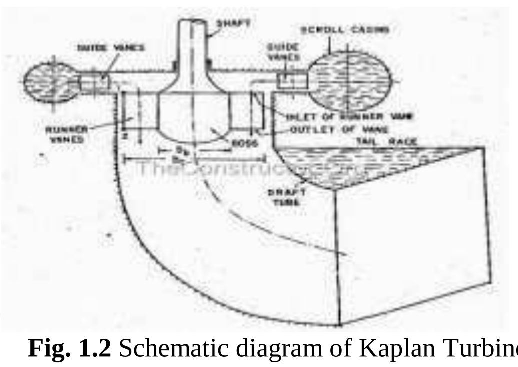


Fig. 1.2 Schematic diagram of Kaplan Turbine

1.2 Working of Kaplan Turbine

The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. The design combines radial and axial features. The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially, through the wicket gate, and spirals on to a propeller shaped runner, causing it to spin. The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy. The turbine does not need to be at the lowest point of water flow, as long as the draft tube remains full of water. A higher turbine location, however, increases the suction that is imparted on the turbine blades by the draft tube. The resulting pressure drop may lead to capitation. Variable geometry of the wicket gate and turbine blades allows efficient operation for a range of flow conditions. Kaplan turbine efficiencies are typically over 90%, but may be lower in very low head applications.

1.3 Applications

Kaplan turbines are widely used throughout the world for electrical power production. They cover the lowest head hydro sites and are especially suited for high flow conditions. Inexpensive micro turbines on the Kaplan turbine model are manufactured for individual power production designed for 3m of head which can work with as little as 0.3m of head at a highly reduced performance provided sufficient water flow. Large Kaplan turbines are individually designed for each site to operate at the highest possible efficiency, typically over 90%. They are very expensive to design, manufacture and install, but operate for decades.

1.4 Variations

The Kaplan turbine is the most widely used of the propeller-type turbines, but several other variations exist:

Propeller turbines have non-adjustable propeller vanes. They are used in where the range of flow power is not large. Commercial products exist for producing several hundred watts from only a few feet of head. Larger propeller turbines produce more than 100 MW. At the La Grande-1 generating station in northern Quebec, 12 propeller turbines generate 1368 MW. Bulb or tubular turbines are designed into the water delivery tube. A large bulb is centered in the water pipe which holds the generator, wicket gate and runner. Tubular turbines are a fully axial design, whereas Kaplan turbines have a radial wicket gate.

The VLH turbine an open flow, very low head "kaplan" turbine slanted at an angle to the water flow. It has a large diameter >3.55m, is low speed using a directly connected shaft mounted permanent magnet alternator with electronic power regulation and is very fish friendly (<5% mortality).are a fixed propeller turbine designed to be immersed in a fast flowing river, either permanently anchored in the river bed, or attached to a boat or barge**.**

1.5 Characteristics of Kaplan turbine

Except for the runner, other components of axial turbine are similar to the mixed-flow turbine.

a. Characteristics of axial turbine:

High speed which is 2 times of mixed-flow turbine when H and N is the same, small size. The runner blades can turn (double adjustment); the turbine has high efficiency when H and N change.

b. Structure of runner:

axial movable-blade turbine is usually used in large hydropower station with low head and large discharge. Main Parts: Blades, hub, main shaft, runner cone, rotating mechanism.

c. Blade:

Curved surface, airfoil section, thick root, thin edge to bear the torque of water flow. Amount of blades: Related to H, generally 4~8 pieces.

d. Blade rotating angle F:

F=0°; when optimum operating condition, the blades begin to turn when F>0, the blades turn to close when F<0. -15°>F<+20°.

e. Hub:

Connected with blades externally, installed rotating mechanism internally.

4 It is installed inside the hub, controlled by governor, high-speed guide vane angle.

II. THEORITICAL CALCULATIONS

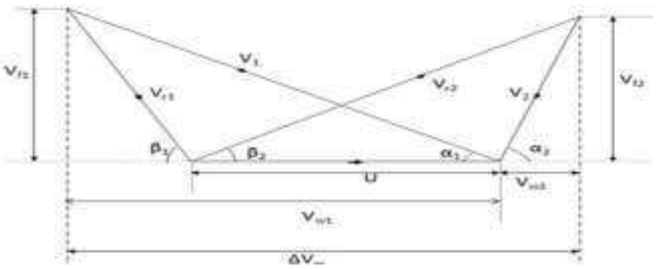


Fig.2.1: Velocity triangle

2.1 Data consideration for calculating Kaplan turbine blade weight

shaft inside radius=14mm

U=Absolute velocity of vane, V=Absolute velocity of jet, V_r=Relative velocity of the fluid after contact with blade

V_w=Tangential component of V (absolute velocity) called whirl velocity

V_f= Flow velocity (axial component in case of axial machines, radial component in case of radial machines

α_1, α_2=Absolute jet inlet, outlet velocity angle, β_1, β_2=Absolute vane inlet, outlet velocity angle

The peripheral velocity at inlet and outlet are equal $u_1=u_2=u=\Pi D_O N/60$, D_O=Outer diameter
Velocity of flow at inlet, outlet are equal $V_{f1}=V_{f2,}$ Area of flow at inlet =Area of flow at outlet
$A= \Pi/4[(D_0)^2-(D_h)^2]$, D_h= diameter of hub, D_O=Outer diameter
1. Area (A) = $\Pi/4[(D_1)^2-(D_h)^2]$ =3.14/4[(86)^2-(28)^2] =5190.42mm ^{2}
2. Discharge (Q) =Ax V_{f1}=5190.42x30 =1.557x10^{-4}m^3/s
3. Blade linear velocity (u) =2 ΠrN/60 =2x3.14x57x144/60 =859.10m/s
α_2=90°, $V_2=V_{f2}$
Euler equation is applicable giving the Euler head (H_e) as
$H_e= V_{w1} u_1 - V_{w2}u_2/g$ (V_{w2}=0)
$H_e = V_{w1} u_1/g$ = 1.716mm
Velocity (V) =$\sqrt{2gh}$ =$\sqrt{2x9.81x1}$=19.6m/s, We assume that V= V_{w1}=19.6m/s
4. Hydraulic efficiency (η_h) = H_e/H= $V_{w1} u_1 - V_{w2}u_2/gH$
H=556-473.43=82.57mm
η_h= 1.716/82.57 = 0.002%
5. Mean radius (r_m) = $(D_0+D_h)/2$ = 86+28/2 = 57mm
6. Absolute jet Inlet velocity angle=$V_{f1}/V_{W1}=\alpha_1$ = 30/19.6=1.53°
Absolute jet Outlet velocity angle α_2=90°
7. Absolute vane inlet velocity angle =V_{f1}/u_1-V_{W1} = 30/859.10-19.6, β_1 = 0.0035°
Absolute vane outlet velocity angle β_2 =V_{f2}/u_2 =30/859.10=0.034°

2.2 Weights of blades

Material	Density(□) kg/m^3	Volume(v) m^3	mass(m) kg	Weight(W) N
Aluminium alloy	27750	7.785x10^{-5}	0.21	2.06
Structural steel	7850	7.785x10^{-5}	0.61	5.98
Titanium alloy	4620	7.785x10^{-5}	0.35	3.43
Stainless steel	7750	7.785x10^{-5}	0.60	5.88

Table 2.1 Weights of blades

III. MODELLING OF KAPLAN TURBINE BLADE

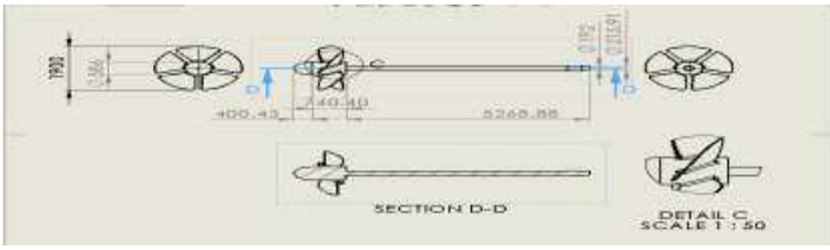
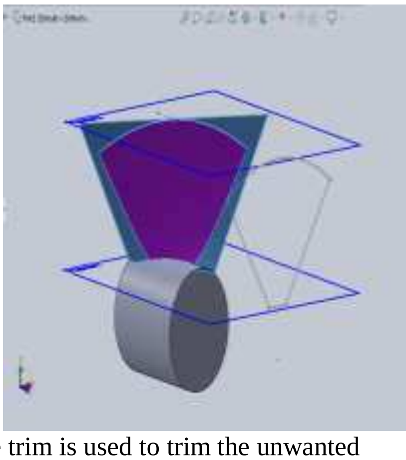


Fig.3.1: Drawing of a turbine blades along with shaft



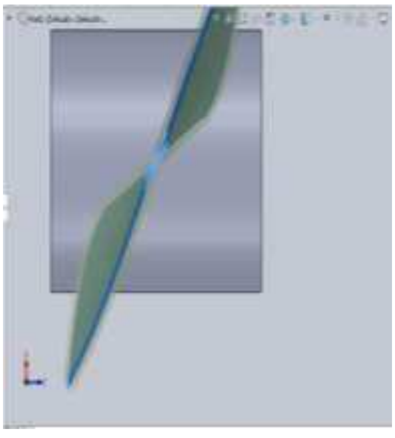


Fig.3.2: Surface trim is used to trim the unwanted portion of the blade

Fig.3.3: Thickness is used to thicken surface loft blad

2.3 Drafting for a turbine assembly

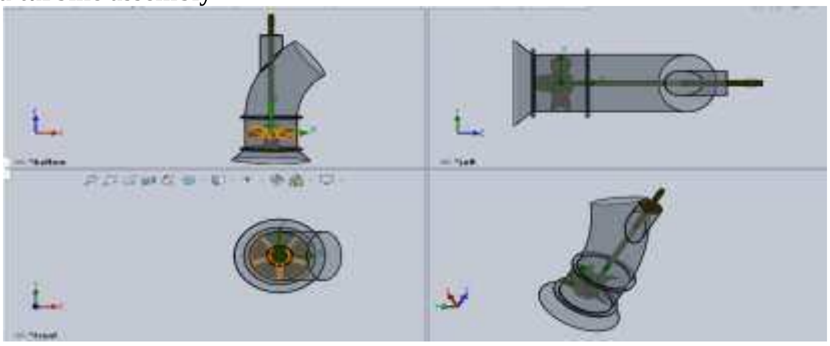


Fig.3.6: Different views of a Kaplan turbine

IV. ANALYSIS OF KAPLAN TURBINE BLADE

4.1 Material properties:

Material	Density (kg/m^3)	Young's modulus (Pa)	Poisons ratio	Bulk modulus (Pa)	Shear modulus (Pa)
Structural steel	7850	2E+11	0.3	1.6667E+11	7.6923E+10
Aluminium alloy	2770	7.1E+10	0.33	6.9608E+10	2.6692E+10
Titanium alloy	4620	9.6E+10	0.36	1.1429E+11	3.529E+10
Stainless steel	7750	1.93E+11	0.31	1.6931E+11	7.3664+10

4.2 Static Structural Analysis of A Kaplan Turbine:

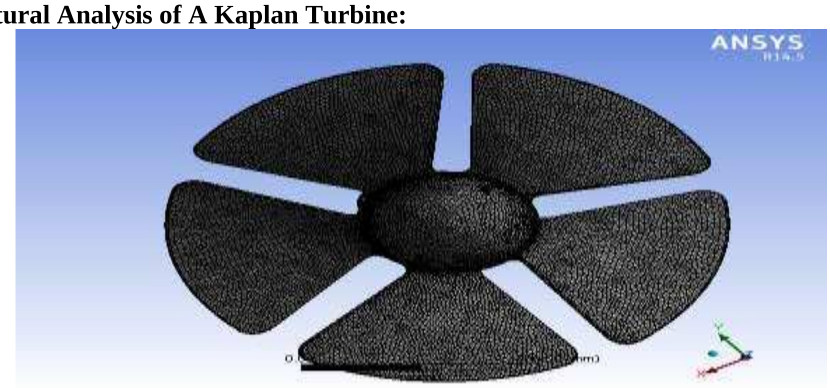


Fig.4.1: Meshing blade

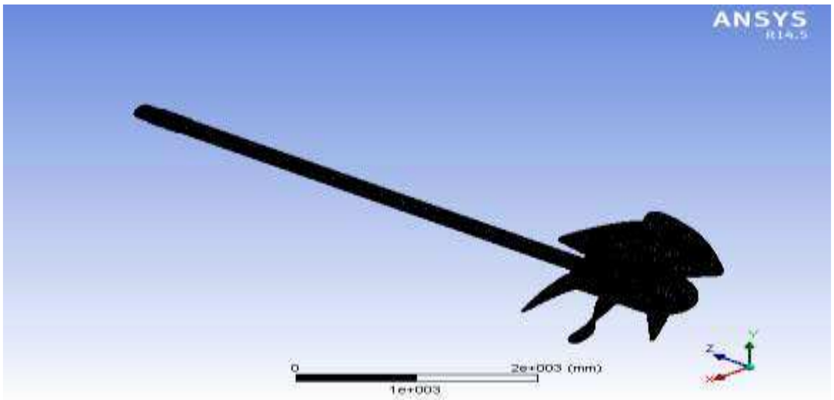


Fig.4.2: Meshing of Kaplan Turbine Runner in Ansys

Static analysis is formed by applying load of 47450N from the literature review

4.2.1 Structural steel

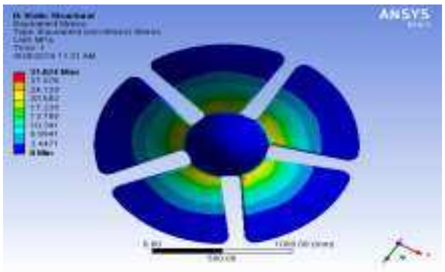


Fig.4.3: Von mises stress

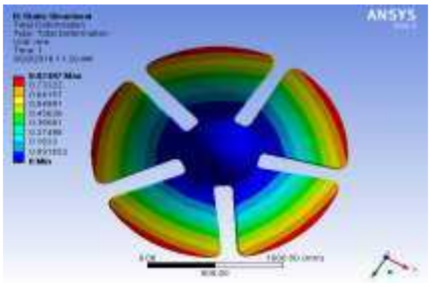


Fig.4.4: Deformatio**n**

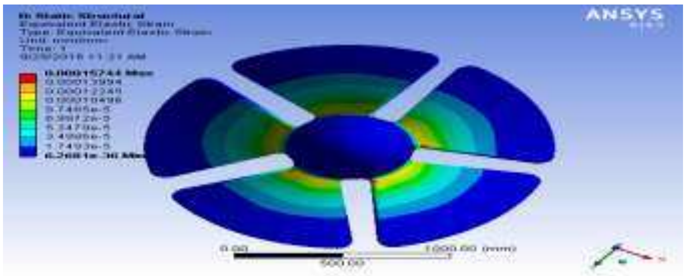


Fig. 4.5: Elastic strain

4.2.2 Aluminium Alloy

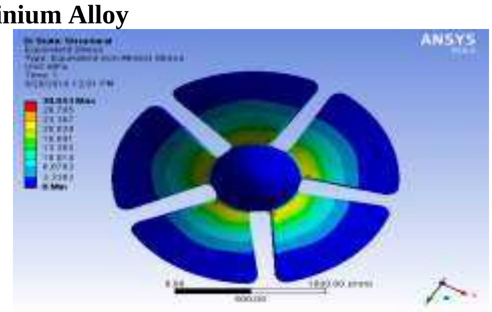


Fig.4.6: Von mises stress

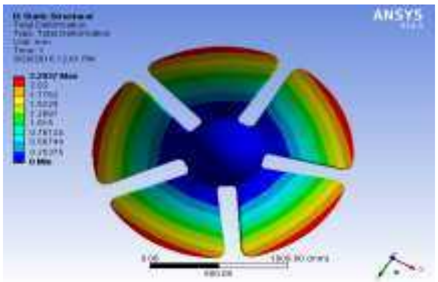


Fig.4.7: Deformation

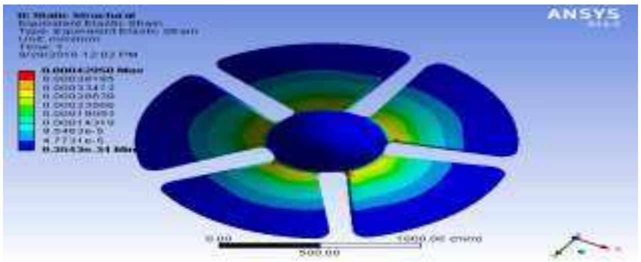


Fig.4.7: Elastic strain

4.2.3 Titanium Alloy

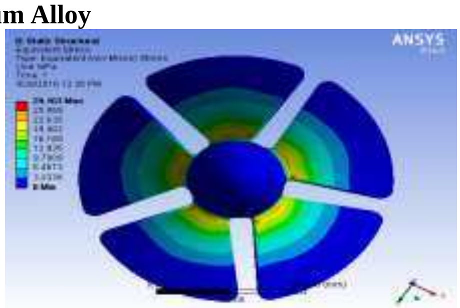


Fig4.8: Von mises stress

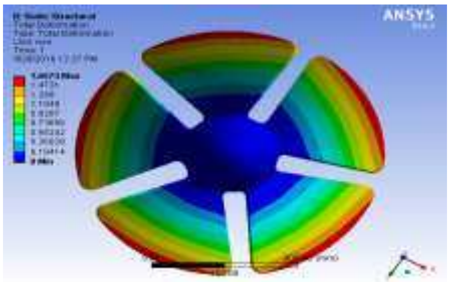


Fig.4.9: Deformation

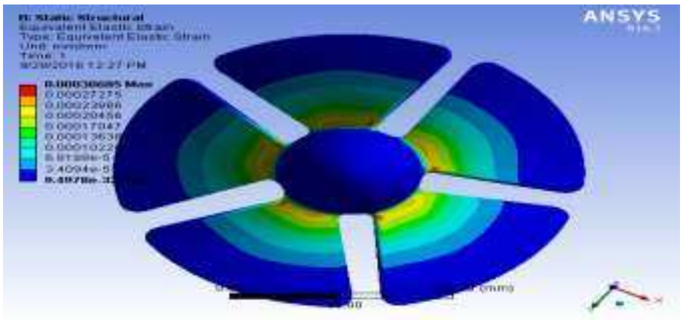


Fig.4.10: Elastic strain

4.2.4 Stainless Steel

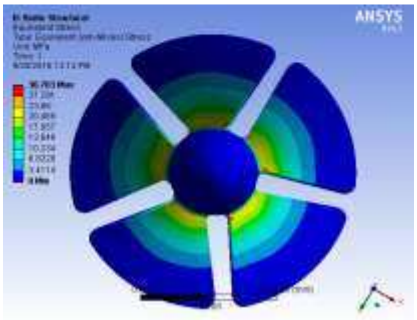


Fig.4.11: Von mises stress

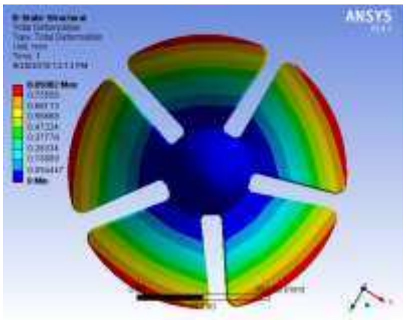


Fig.4.12: Deformation

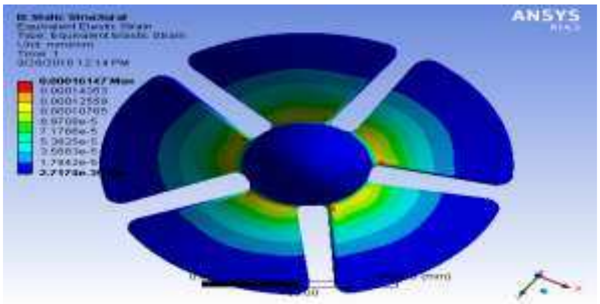
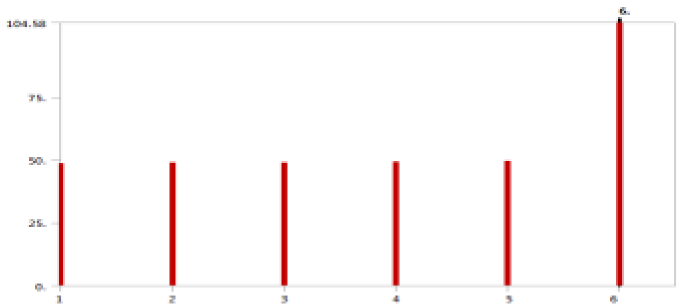


Fig.4.13: Elastic Strain

4.3 Modal Analysis



4.14 Variation of number of modes Vs frequency. X-axis contains number of modes and Y-axis contains frequency

4.4 Cfd Analysis

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with Surfaces defined by boundary condition. CFD enables scientist and engineers to perform numerical experiments, i.e. Computer simulations in a virtual flow laboratory. CFD is faster and definitely cheaper.

4.4.1 Cut plots of CFD analysis

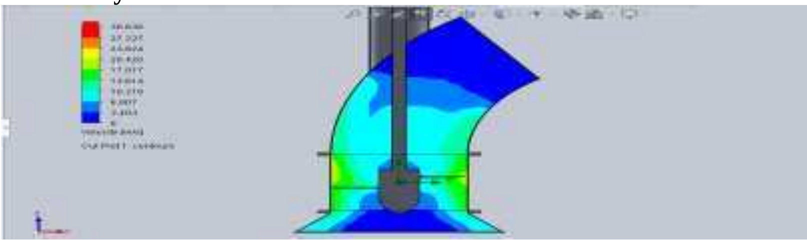


Fig.4.15: Velocity variation

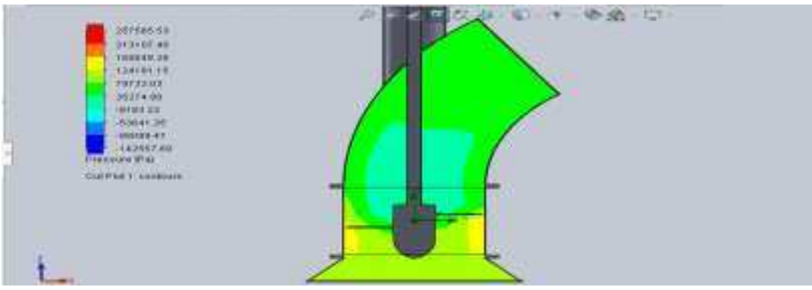


Fig.4.16: Pressure variation

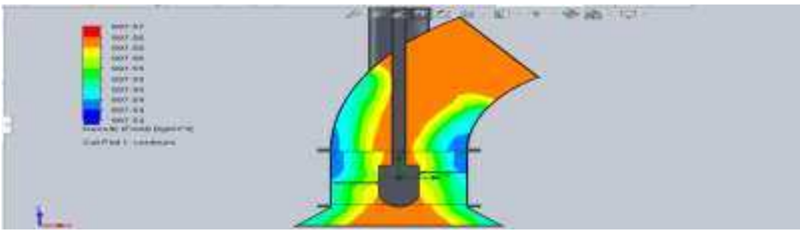


Fig.4.17: Density variation

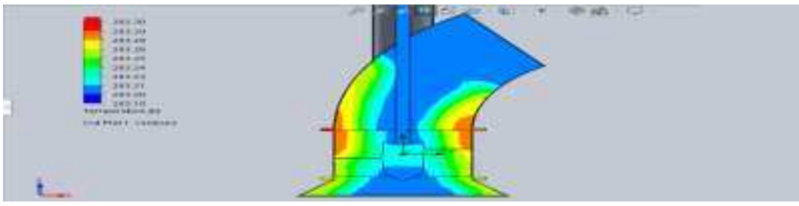


Fig.4.18: Temperature Distribution

4.4.2 Flow trajectory values of CFD analysis

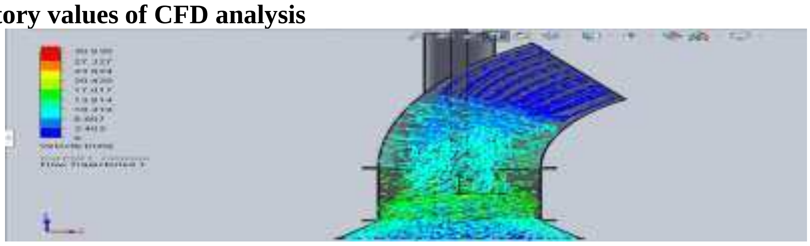


Fig.4.19: Velocity flow

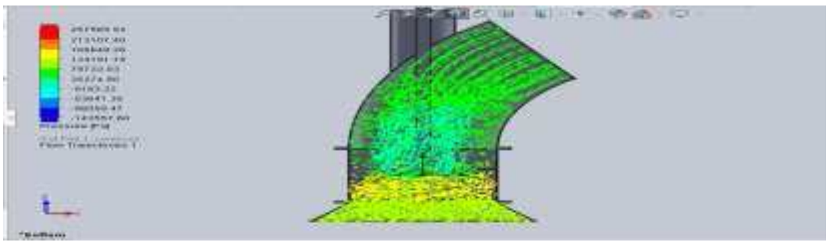


Fig.4.20: Pressure flow

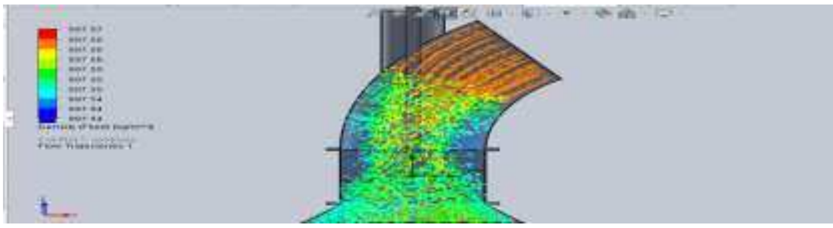


Fig.4.21: Density flow

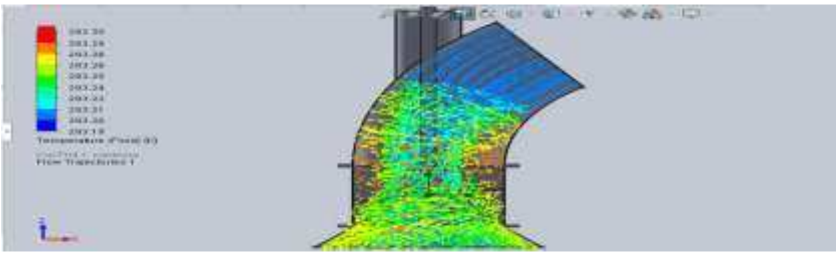


Fig.4.22: Temperature Distribution

VI. RESULTS

6. 1 Static Structural Analysis Results

Material	Max stress (MPa)	Total deformation(mm)	Max strain(mm)
Structural steel	31.024	0.02487	0.00015744
Aluminium alloy	30.043	2.2837	0.00042958
Titanium alloy	29.103	1.6573	0.00030685
Stainless steel	30.703	0.85002	0.00016417

6.2 Modal Analysis Results:

6.2.1 Total deformation:

Material	M1(mm)	M2(mm)	M3(mm)	M4(mm)	M5(mm)	M6(mm)
Structural steel	3.9224	3.6507	3.7987	3.3472	3.5216	1.4045
Aluminium alloy	6.5757	6.1076	6.3872	5.6333	5.9363	2.3723
Titanium alloy	5.0707	4.701	4.9339	4.3678	4.6021	1.8476
Stainless steel	3.9421	3.6666	3.822	3.368	3.5459	1.4148

6.2.2 Frequencies:

Material	F1(Hz)	F2(Hz)	F3(Hz)	F4(Hz)	F5(Hz)	F6(Hz)
Structural steel	48.375	48.695	48.819	49.145	49.342	104.58
Aluminium alloy	49.008	49.347	49.459	49.803	50.003	105.28
Titanium alloy	44.628	44.951	45.041	45.366	45.548	95.326
Stainless steel	47.98	48.302	48.421	48.748	48.944	103.5

6.2.3 CFD cut plot results:

Velocity (m/s)	30.630
Pressure (pa)	257585.53
Temperature (k)	997.57
Density (kg/m^3)	293.30

VII. CONCLUSIONS

- The stress (Von-Misses) and maximum stress developed at the runner blades are maximum at joints between the hub and runner blade however their valves are less the ultimate tensile strength of the runner blade material. Maximum principle stress is also in the safe limits. Hence all the stresses developed at the turbine runner blades are safe and no major failure is recorded during the static structural analysis.
- The modal analysis shows no resonance in any of the four mode shapes. The natural frequency of all mode shape does not match with the natural frequency of the runner blade. Hence no resonance produced during the modal analysis. The blade acts as a fixed cantilever beam during the modal analysis where the displacement is high but in safe limits at the edges of the runner blade for all mode shapes.
- By comparison of the results, we got that titanium has a low weight. Next one is aluminium alloy. We selected best material is titanium alloy.

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