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Design and Static Analysis of Micro Hydro Kaplan Turbine Blade

Authors
Karthik A.S.[1], Arun S.Menasinkai[2], Chetan C.Kokatnur[3], Dr.S.N.Kurbet[4]
[1]Basaveshwar Engineer College, Mechanical Department
Vidyagiri , Bagalkot-587102, India
Karthik.bvb2@gmail.com
[2]Basaveshwar Engineer College, Mechanical Department
Vidyagiri , Bagalkot-587102, India
Arunmen446@email.com
[3]Basaveshwar EngineeringCollege,Mechanical Department
Vidyagiri, Bagalkot-587102,India
Ckokatnur@email.com
[4]Basaveshwara Engineering College.Mechanical Department
Vidyagiri, Bagalkot-587102,India
kurbetsn@rediff.com

Abstract:
Vital efforts are needed all over the world to develop Micro Hydro Kaplan Turbine used to generate electricity for domestic purpose.Due to increase of electricity tariff in last few years small Hydro Turbine plants become effective.Since the runner of a Micro Turbine plant is quite small, it has to be examined if the hub of the runner provides enough room for proper adaptation mechanism. In this context potential height of 50 feet is assumed on basis of which main characteristics of runner blades are determined.Then,Important data like flow rate and parameters of runner blades are establised for modeling of turbine and detailed stress analysis is carried out in Ansys software.

Keywords:Turbines,CATIA V5,ANSYS

1. Introduction

Hydraulic (water) turbines are the machines which convert the water energy (Hydro-power) into Mechanical energy. The water energy may be either in the form of potential energy as we find in dams, reservoirs, or in the form of kinetic energy in flowing water. The shaft of the turbine directly coupled to the electric generator which converts mechanical energy in to electrical energy. This is known as "Hydro-Electric power".

The Kaplan Turbine is a propeller Turbine which has adjustable blades. It was developed in 1913 by Austrian professor Viktor Kaplan, who combined automatically adjusted propeller blades with automatically adjusted wicket gates to achieve efficiency over a wide range of flow and water level. The Kaplan Turbine was an evolution of the Francis Turbine. Its invention allowed efficient power production in low-head applications that was not possible with Francis Turbines. The head ranges from 10-70meters and output from 5-200MW.

The Propeller turbine and the Kaplan turbine are reaction turbines. They have relatively small dimensions combined with a high rational speed. Hence the generator dimension is rather small and inexpensive. In addition, both the Propeller and the Kaplan turbines show a large overload capacity. The intake of the flow is radial. After the inlet the flow makes a right angle turn and enters the runner in an axial direction.The difference between the Propeller and Kaplan turbines is that the Propeller turbine has fixed runner blades while the Kaplan turbine has adjustable runner blades. Propeller turbines can only be used on sites with a comparatively constant flow and head while Kaplan turbines are quite flexible. The Kaplan turbine can be divided in double and single regulated turbines. A Kaplan turbine with adjustable runner blades and adjustable guide vanes is double regulated while one with only adjustable runner blades is single regulated. The application of Kaplan turbines are from a head of 2m to 40m. The advantage of the double regulated turbines is that they can be used in a wider field. The double regulated Kaplan turbines can work between 15% and 100% of the maximum design discharge single regulated turbines, however, can only work between 30% and 100% of the maximum design discharge.

Timo Flaspohler(2007), made a study on design of the runner of a Kaplan turbine. As the runner of the small hydroelectric power point is quite small,the proper adaptation mechanism is to be checked.then the main characteristics of runner are determined and forces acting on blade are found .then the detailed stress analysis is carried out.[1]

Viorel C. Câmpian, Gabriela Mărginean et al., made the study on failure analysis of a Kaplan turbine runner blade from a hydropower station in Romania. In order to determine the causes that led to the cracks, first carried out metallographic investigations on a sample obtained from the cracked blade. Cracking of the blade was caused by fatigue, initiated by the numerous non metallic inclusions. They led to the conclusion that the cracking of the blade started and developed from the stress concentrator placed between blade and blade flange on leading edge direction.[2]

2. Calculation Of The Main Characteristics

The main characteristics are the data on which the design of the runner is based. To calculate, for instance, the forces on the blade or to determine the dimensions of the adaptation mechanism the characteristics of the turbine are needed.

2.1Discharge Through Runner

Discharge through runner can be calculated with following equation[3].

$Discharge\ = Q = A * V$
$Area\ = (\pi * d^2)/4$
$d = diameter\ of\ pipe\ 6inch$
$d = 0.1524m$
$Area\ = 0.018m^2.$
$Velocity = V$
$V^2 - U^2 = 2 * a * s$
$V^2\ = 2 * a * s$
$[initial\ velocity \quad U = 0]$
$V = 17.15m/s.$
$Discharge\ = Q = 0.308m^3/s.$

2.2Power That Can Be Generated

$P = 9.81 * \eta * Q * H$
$P = 9.81 * 0.9 * 0.308 * 15$
$P = 40.78KW$

The efficiency depends on the level of the losses which depend on the construction of the water passage of the turbine. However, the design of the runner is just theoretical. This means that the runner is not designed for a specific plant and the water passage does not exist. Thus, the value of efficiency must be assumed. The site

where the experimental rig of the turbine can be built provides a maximum gross head of 15m. An efficiency of 0.9 can be assumed for a Kaplan turbine.[1]

2.3Runner Diameter Section

The runner diameter D can be calculated by the following equation[3].

$Discharge\ = Q\ = \pi/4\,(D^2 - d^2)\,\Psi\,\sqrt{}\,(2 * g * h)$
$\Psi = flow\ ratio$
$d/D = \Psi \qquad [0.35 < \Psi < 0.75]$
$0.308 = \frac{\pi}{4} D^2\ (1 - 0.352)\ 0.35\ \sqrt{}\ (2 * 9.81 * 15)$
$D = 0.27cm.$
$D = 270mm.$

2.4 Hub Diameter

The hub diameter d can be calculated with the following equation[3].

$d/D = 0.35$
$d = 0.35 * 0.27$
$d = 9cm.$
$d = 90mm.$

3.Calculations Of Forces

The tangential and axial forces acting forces acting on the Blade are as shown in figure.1[1].

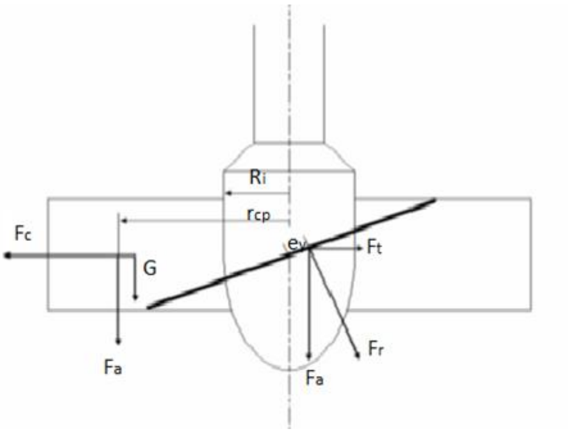

Figure1:forces acting on blade

3.1 Tangential force is defined as[4].

$F_t\ =\ P/(2 * \pi * n * z * r_{cp})$

$P\ =\ Power \qquad [watt]$

$z\ =\ no.of.Blades$

$n\ =\ specific\ speed \qquad [rad/sec]$

$r_{cp}\ =\ radius\ of\ center\ of\ pressure \quad [m]$

$r_{cp}\ =\ \sqrt{}(.0452 + .1352)/2$

$=\ 0.1006m.$

$F_t\ =\ 40{,}000/(2 * \pi * 51 * 4 * 0.1006)$

$=\ 310N.$

3.2 Axial Force

Assuming that the water is dormant and the blade is a plate, the force Fa, which is caused by the water, can be approximately calculated with the following equation[1].

$F_a\ =\ g * \rho * H_n * A_b$

$Sweep\ angle\ = 800$

$g\ =\ gravity \quad [m/s^2]$

$\rho\ =\ density\ of\ water \quad [kg/m^3]$

$H_n\ =\ net\ head \qquad [m]$

$A_b\ =\ Area\ of\ the\ blade \quad [m^2]$

$Area\ of\ the\ blade\ can\ be\ calculated\ by$:

$$A_b = \pi * 80(0.1352 - 0.0452)/360$$
$$= 0.011m^2.$$
$$F_a = 9.81 * 1000 * 13.5 * 0.011$$
$$= 1456.785N.$$

3.3 Resulting Force

$$F_r = \sqrt{(3102 + 14562)}$$
$$= 1489N.$$

4. Linear Static Analysis Of Blade Using Ansys

The study is made with the ANSYS workbench software, which offers a wide range of advanced type analysis. Here, in this study a comparison is made by varying number of Blades in operation and by varying stress relief grooves on flange[2].

Loads and supports applied on blade:

- Fixed type constraint applied to the flange holes,which imposes 0 value to the translations and rotation to selected entities.
- Axial and Tangential forces are acting on the surface of the Blade.
- Standard Earth gravity is applied.

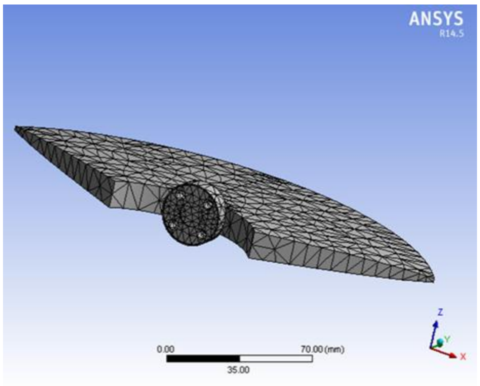

Figure 2:Tetra Meshing

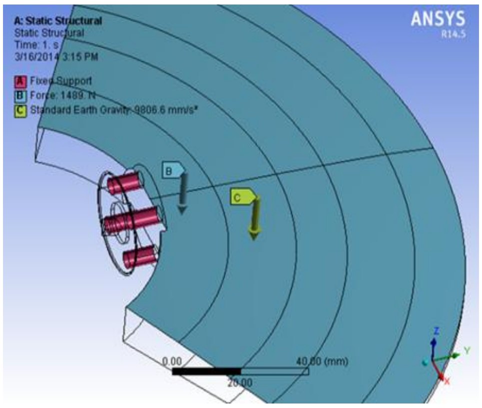

Figure 3.Loads And Restrictions Applied

4.1 Case 1: In first case we consider four Blades for power generation. Tangential force depends on the Number of Blades in operation.For four blades the Resultant force of 1489N is developed.

- Force=1489N.
- Number of Blades=four.
- Stress relieve grooves on flange[5mm Diameter with four holes, Eight holes].
- Stress relieve grooves on flange[7mm Diameter with four holes, Eight holes].

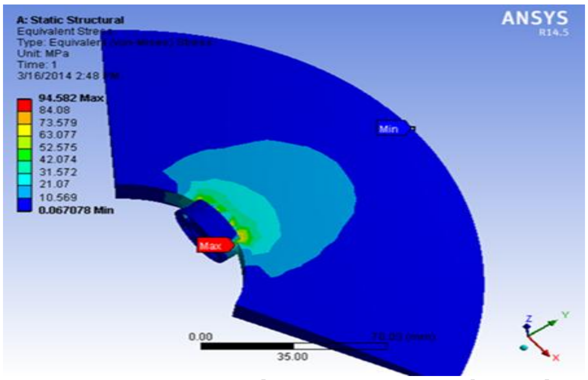

Figure 4. Stress Result For 5mm Dia With 4 Holes

Table 1.von-Mises Stress values for case 1

Von-Mises Stress	No.of holes	5mm dia	7mm dia
	4	94.582MPa	71.07MPa
	8	84.536MPa	90.265MPa

4.2 Case 2: In Second case we consider six Blades for power generation. Tangential force depends on the Number of Blades in operation. As the Number of Blades increases the tangential force decreases Hence, changing the resultant force.For four blades the Resultant force of 1470N is developed.

- Force=1470N.
- Number of Blades=six.
- Stress relieve grooves on flange[5mm Diameter with four holes, Eight holes].

- Stress relieve grooves on flange[7mm Diameter with four holes, Eight holes].

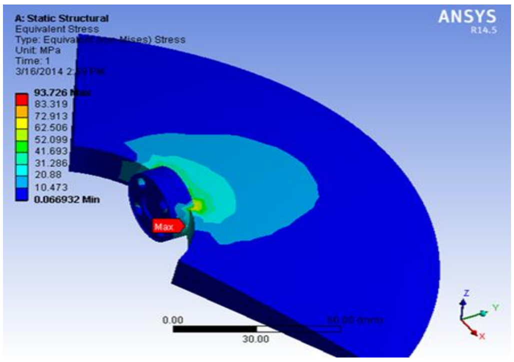

Figure 5.Stress Result For 5mm Dia With 4 Holes

Table 2. Von-Mises Stress Values For Case 2

Von-Mises Stress	No.of holes	5mm dia	7mm dia
	4	93.726MPa	70.17MPa
	8	83.659MPa	89.113MPa

5. Conclusions

The Calculations carried out lead to conclusions that 40KW power can be generated by using a potential head of 50feet. The adaptation mechanism in this report is different to the adaptation mechanisms found in the literature. This is based on the small space the hub provides. However, even though the space of the hub is little, it is enough to fit a proper mechanism with which to adjust the blades. The stress analysis show that the adaptation mechanism should be able to withstand the occurring forces. To design the runner some simplifications and assumptions had to be made, as it is only tests can really confirm that the adaptation mechanism is sufficient. However, the safety factor used in the stress analysis should be high enough to avoid any significant malfunction.

As per the comparison of Table.1 and Table.2 we can see that as we go on increasing the number of Blades the force acting on the Blades reduces. But the material cost increases with increasing number of Blades. Here, we have considered two cases where an attempt is made to study the Von-Mises stress behavior of blades with increasing diameter and increasing number of holes. We can see that there is only small amount of stress change comparing with number of Blades. Then, the study is made by increasing the diameter of the holes .From comparison of tables we can conclude that by increasingthe diameter of stress relieve grooves the amount of stress generated is less, As per our study 7mm diameter with four holes gives minimum stress genereation in component. And the conclusions are totally based on static Analysis assuming plate to be flat,practically the stresses occurring may be different with changing curvatures of Blades.

The Future scope of work is to carry out the Fluid flow Analysis and stress occurring in these cases will be totally different from existing one.

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