

# Design and Analysis of the Effect of Guide Vanes on the Wells Turbine

Rakesh Prajapati<sup>1</sup>, Nirav Parikh<sup>2</sup>, Saurabh Modi<sup>3</sup>, Brijesh Makwana<sup>4</sup>

Assistant Professor, Department of Mechanical Engineering, Parul Institute of Technology, Vadodara, Gujarat, India<sup>1</sup>

Assistant Professor, Department of Mechanical Engineering, Parul Institute of Technology, Vadodara, Gujarat, India<sup>2</sup>

Assistant Professor, Department of Mechanical Engineering, Parul Institute of Technology, Vadodara, Gujarat, India<sup>3</sup>

Assistant Professor, Department of Mechanical Engineering, Parul Institute of Technology, Vadodara, Gujarat, India<sup>3</sup>

**ABSTRACT:** The method of wave energy conversion utilizes an oscillating water column (OWC). The OWC converts wave energy into low-pressure pneumatic energy in the form of bidirectional airflow. Wells turbine with its zero blade pitch setting has been used to convert this pneumatic power into unidirectional mechanical shaft power. The periodic wave movements assist the flow of air in the turbine which gives a bidirectional flow in the turbine and hence a zero blade pitch setting is used to produce rotation in one direction to get the necessary power output and desired torque. But a Wells turbine has inherent disadvantages like lower efficiency and poorer starting characteristics. To improve the starting and running characteristics many experimental and numerical studies have been done based on different parameters. Providing guide vanes on either side of the rotor could be one of the most effective ways of improving its performance. Some papers have demonstrated the usefulness of 2D guide vanes and some experimental studies are also done based on that. In order to achieve further improvement in the performance of the Wells turbine, the effect of different configurations of guide vanes will be studied. The guide vanes are said to increase the efficiency of the turbine by increasing the power output of the turbine.

**KEYWORDS:** Wells Turbine, Guide Vanes, OWC.

## I. INTRODUCTION

Energy is a basic input to the national economy, both agricultural and industrial, apart from being an instrument for improving the quality of life. The primary commercial energy inputs to the Indian economy are from coal, oils, and hydroelectricity and to a limited extent nuclear energy.

**Energy – Current Status** India is the fourth largest energy consumer in the world after the United States, China, and Russia. Primary energy consumption in India has more than doubled between 1990 and 2012. The country has the second largest population in the world, at more than 1.2 billion people in 2012, growing about 1.3% each year since 2008. In the International Energy Outlook 2013, EIA projects India and China will account for about half of global energy demand growth through 2040, with India's energy demand growing at 2.8% per year.

Concerns about carbon dioxide and global warming and the security and long term availability of fossil fuel supplies has led to greatly renewed interest in all forms of renewable energy and so the time may have come for ocean renewable energy.

### 1. Wave Power as a Renewable Energy

The globally distributed resources and relatively high energy density associated with most ocean energy sources provide ocean energy with the potential to make an important contribution to energy supply in the coming decades, if technical challenges can be overcome and costs thereby reduced. Accordingly, a range of initiatives are being employed to promote and accelerate the development and deployment of ocean energy technologies. In India's perspective, there is tremendous scope for the energy from the ocean as India has a long coastline of about 7500 km and about 336 islands in Bay of Bengal and Arabian Sea.

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Vol. 7, Issue 1, January 2018

The ocean can produce two types of energy, thermal energy from the sun's heat, and mechanical energy from the tides and waves. Tides are driven primarily by the gravitational pull of the moon, and waves are driven primarily by the winds. As a result, tides and waves are intermittent sources of energy. But to extract wave energy one requires an effective wave energy converter.

Among wide range of wave energy conversion devices Oscillating Water column is one of the most mature and promising device. It consists of a chamber with an opening to the sea below the waterline. As waves approach the device, water is forced into the chamber, applying pressure on the air within the chamber. This air escapes to atmosphere through a turbine.

For simplicity, the air turbine normally selected is of a self-rectifying form so that whether the collector is exhaling or inhaling, the turbine is driven in the same direction. Over the period of time many different types of turbines for wave energy conversion have been developed. Among them the most economical self-rectifying turbines used for wave energy power conversion is Wells Turbine. In its simplest form the air turbine rotor consists of several symmetrical airfoil blades positioned around a hub.

## 2. About Oscillating Water Column and Wells Turbine

The Wells turbine is a self-rectifying air turbine which is expected to be widely used in wave energy devices with the OWC. There are many researches which describe the performance of the Wells turbine both at starting and running characteristics. According to reports the Wells turbine has inherent disadvantages like lower efficiency and poorer starting characteristics. To overcome these disadvantages different experimental and computational studies are done on various performance parameters and other methods to improve the performance of wells turbine.

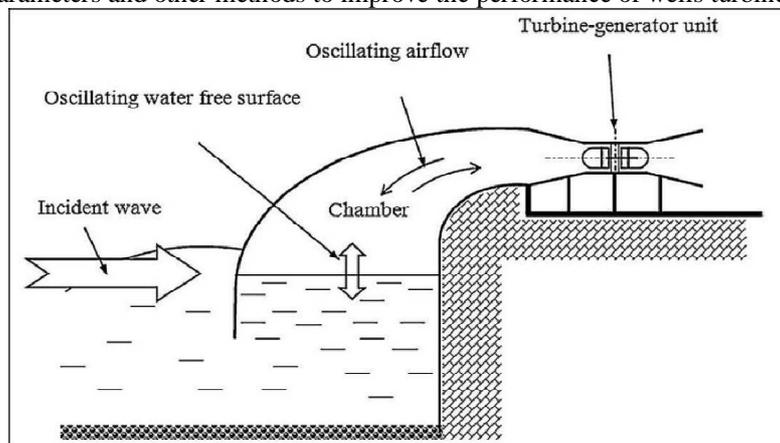


Fig.1. Oscillating water column

An OWC consists of a chamber with an opening to the sea below the waterline. As waves approach the device, water is forced into the chamber, applying pressure on the air within the chamber. This air escapes to atmosphere through a turbine. As the water retreats, air is then drawn in through the turbine. A low-pressure Wells turbine is often used in this application as it rotates in the same direction irrespective of the flow direction, removing the need to rectify the airflow. It has been suggested that one of the advantages of the OWC concept is its simplicity and robustness.

## 3. Principle of Operation

Figure shows a blade in motion at the design speed  $U$  in a flow with an upward, absolute axial velocity  $c_1$ . It can be seen that the relative velocity  $v_1$  is inclined to the chord line of the blade at an angle  $\alpha$ . According to classical aerofoil theory, an isolated aerofoil at an angle of incidence  $\alpha$  to a free stream will generate a lift force  $L$  normal to the direction of the free stream. In a viscous fluid the aerofoil will also experience a drag force  $D$  in the direction of the free stream. These lift and drag forces can be resolved into the components of force  $X$  and  $Y$ . i.e.

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Vol. 7, Issue 1, January 2018

The force  $Y$  acts in the direction of blade motion, giving positive work production. The turbine absorbs the axial force while the tangential force causes the turbine to rotate. For a symmetrical aerofoil the direction of tangential force is the same for both positive and negative values of  $\alpha$ . Therefore, the direction of rotation of the rotor is independent of airflow direction.

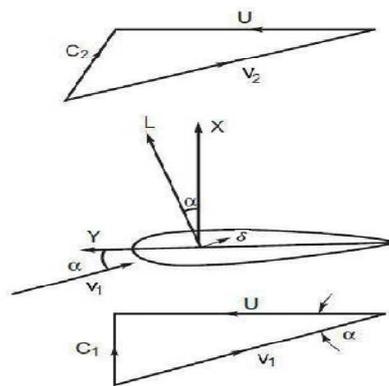


Fig.2 Velocity and Force vectors acting on aerofoil

## II. OBJECTIVES

1. According to various researches the Wells turbine has disadvantages like lower efficiency and poorer starting characteristics.
2. To overcome these disadvantages studies are done on various performance parameters to improve the performance of wells turbine.
3. Providing guide vanes either side of rotor could be one of the most effective ways of improving its performance.
4. To investigate the performance of wells turbine with guide vanes for wave energy conversion.

## III. LITERATURE REVIEW

**Pierpaolo Puddu** et al. done the experimental study of the flow in a Wells turbine submitted to an unsteady and bi-directional airflow. The investigations were carried out on a set-up that can simulate the real operating conditions of a wave energy conversion device using a two-dimensional hot-wire anemometer probe. In addition to local measurements, the position of the piston that simulates the wave motion, the driving torque and the turbine rotational speed were also measured. These surveys allowed determination of the turbine instantaneous performances by analysing the aerodynamic flow characteristic at mid-span in the blade-to-blade plane downstream of the rotor. Many tests were carried out at fixed time periods of 9 s and at different rotational velocities of the turbine for both inflow and outflow phases. They found that the turbine performs better during the outflow phase compared to the inflow phase. This difference is due to the asymmetry of the inlet flow between the two phases. Further they noticed that the hysteresis can be noticed only during the outflow phases and is negligible in the inflow phase.

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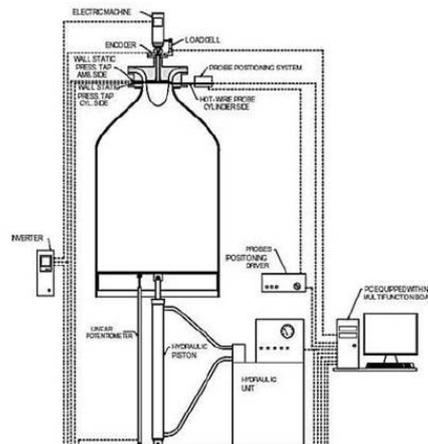


Fig.3 Scheme of the experimental set-up by Pierpaolo Puddu

**Shinya Okuhara** et al. propose Wells turbine with booster turbine for wave energy conversion, in order to improve the performance of wells turbine. The performance of turbines under steady flow conditions has been investigated experimentally by model testing. Furthermore, estimated mean efficiency of the turbine by quasi-steady analysis. Author observed that the peak mean efficiency decreases with the increase of  $DW/Di$  when turbine diameter ratio  $DW/Di \leq 1.2$ . The peak mean efficiency increase with  $DW/Di$  when turbine diameter ratio  $DW/Di \geq 1.2$ . The peak mean efficiency is lower than that of single wells turbine.

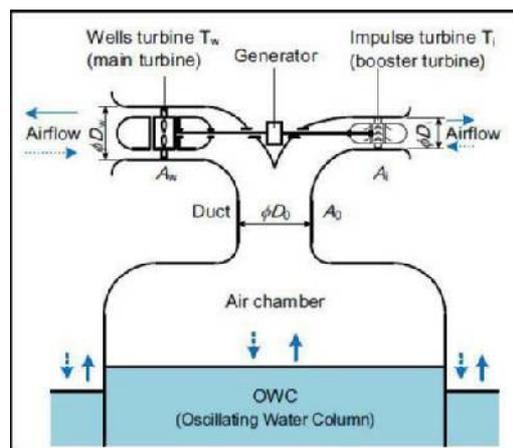


Fig.4. Principle of plant using Wells turbine with booster turbine

However, mean efficiency at high flow coefficient in the case of Wells turbine with booster is higher than that of single Wells turbine. Finally they concluded that the mean efficiency of turbine strongly depends upon turbine diameter ratio and it can be improved by adding a booster turbine.

**Maurizio Paderi** et al. did experimental study of flow through a Wells turbine with NACA0015 profiles submitted to an unsteady and bi-directional flow. He used the same experimental setup as in [P9] based on the principle of an oscillating water column (OWC) equipped with a Wells turbine. Several test campaigns were carried out with a constant, while the period was varied in the range between 7 and 9 s and the performance of the Wells turbine was presented using the dimensionless coefficients of total pressure, torque and efficiency versus the flow coefficient.

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Vol. 7, Issue 1, January 2018

After several tests they found a strong asymmetry of the inlet flow between the phases of inflow and outflow and also shown that the maximum efficiency of the turbine is always obtained for values of the flow coefficient between 0.19 and 0.21.

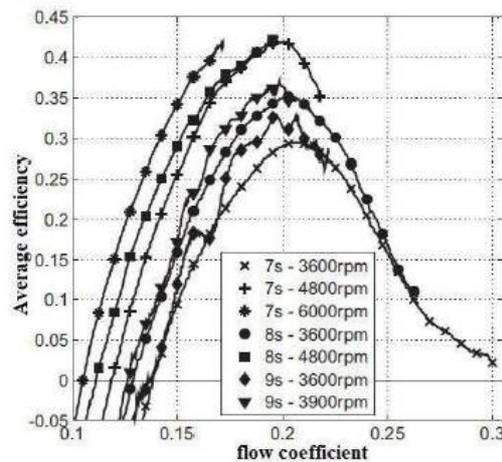


Fig.5. Averaged efficiency as a function of flow coefficient for several test conditions

From the literature we found the parameters that affect the functioning of wells turbine. The effects of some of the parameters on the performance of the Wells turbine are discussed in the following sections.

## IV. CALCULATIONS

From the study of the literature review the optimum parameters obtained are given in the table 1 For validation purpose the dimensions are taken from the experimental study by T.Setguchi.

**Table 1** Wells Turbine Configurations

1	Blade Profile	NACA 0021
2	Blade Chord Length	75mm
3	Number of Blades	8
4	Solidity at mean radius	0.75
5	Duct Diameter	300mm
6	Tip Clearance	1mm
7	Hub to Tip ratio	0.7
8	Aspect ratio	0.6

- The Tip Diameter  
Tip Diameter,  $D_t = D_d - (2 \cdot \text{tip clearance})$   
 $D_t = 300 - (2 \cdot 1) = 298 \text{ mm.}$

- The Blade Length,  
Aspect Ratio,  $AR_w = l_w / c_w$   
 $L_w = AR_w \cdot c_w$   
 $L_w = 0.675$   
Length of the blade,  
 $L_w = 45 \text{ mm}$

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Vol. 7, Issue 1, January 2018

- The Hub Diameter,  
Hub Diameter  $D_h = D_t - 2l_w$   
 $D_h = 298 - (2 \cdot 45)$   
Diameter of hub,  $D_h = 208\text{mm}$

- Blade Sweep  
Blade sweep,  $f = 0.35 \cdot c_w$   
 $f = 0.35 \cdot 75$   
Blade sweep =  $26.25\text{mm}$

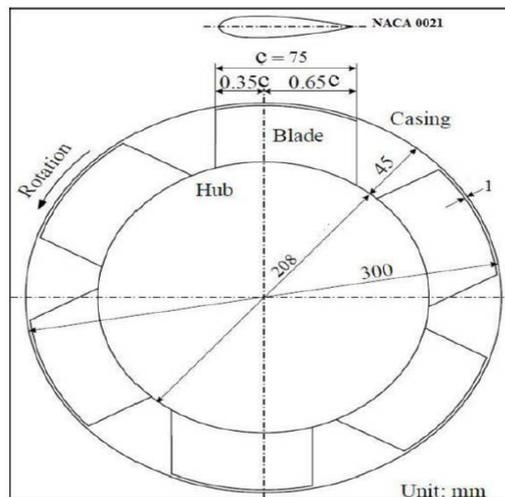


Fig.5. Conditions Wells turbine configurations

## 1. Design of Guide Vanes

For the simplicity circular arc profiles are selected for guide vanes. Guide vanes are symmetrically installed at a distance both downstream and upstream of the rotor as shown in Fig. 3.2. The leading and trailing edges are rounded to a semi-circle of radius 0.5 mm. The aspect Ratio for guide vanes is kept 0.58. So the blade length can be obtained as,

$$AR_g = l_g / c_g$$

$$l_g = AR_g \cdot c_g$$

$$l_g = 0.58 \cdot 77$$

$$\text{Guide vane length } l_g = 44.7 \text{ mm}$$

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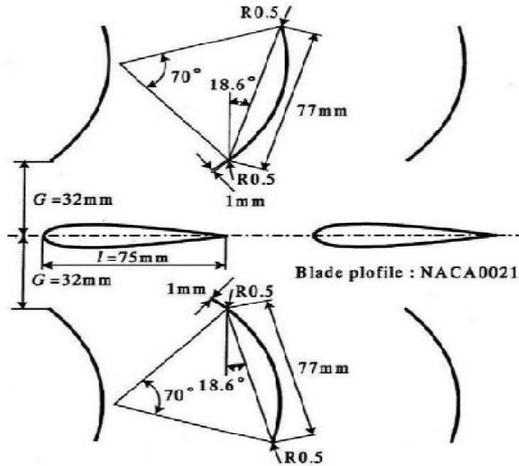


Fig.6. Guide Vanes Configuration

Table 2 Guide Vanes Configuration

1	Guide Vanes Profile	Circular
2	Chord Length	77 mm
3	Gap between Guide Vanes and Turbine	32 mm
4	Number of Guide Vanes	13
5	Camber Angle	70
6	Gap to Chord ratio	0.43
7	Stagger Angle	18.6
8	Length of Guide Vanes	44.7 mm

## V. MODELLING AND ANALYSIS

Using above configurations model is created using PTC CREO 2 software. As it is parametric modelling software, it provides ease to generate Aerofoil. Model is extended 4 times of chord length at inlet and 8 times of chord length at outlet. As the wells turbine is a rotating domain, whole geometry is modelled in three parts,

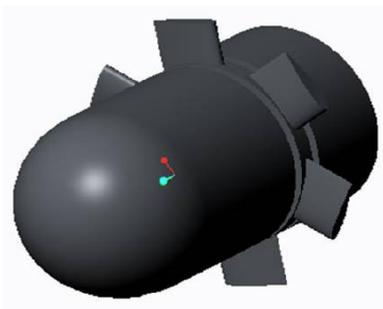


Fig.7. Modelling in Cre-O Software

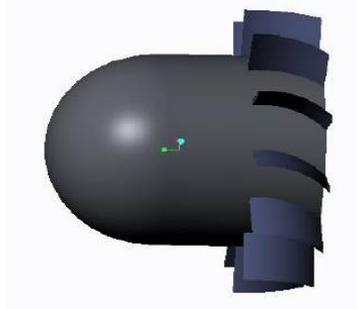


Fig.8. Wells Turbine Section

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Vol. 7, Issue 1, January 2018

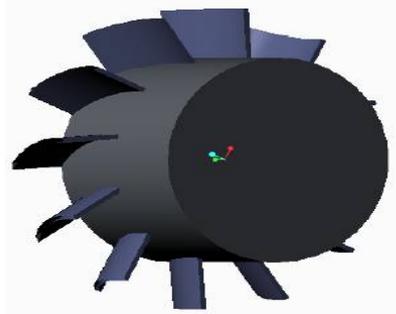


Fig.9. Outlet section with guide vanes

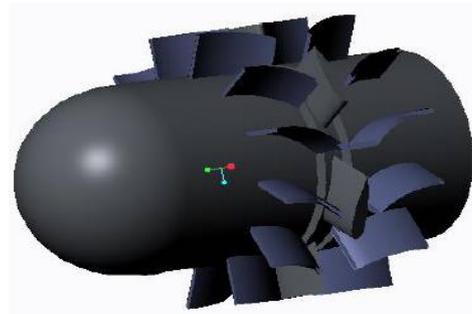


Fig.10. Assembly guide vanes

The analysis was carried out in ansys CFX. First the model made in CRE-O parametric was imported in the ansys. The geometry was initially converted into mesh (medium mesh) over which analysis was to be carried out.

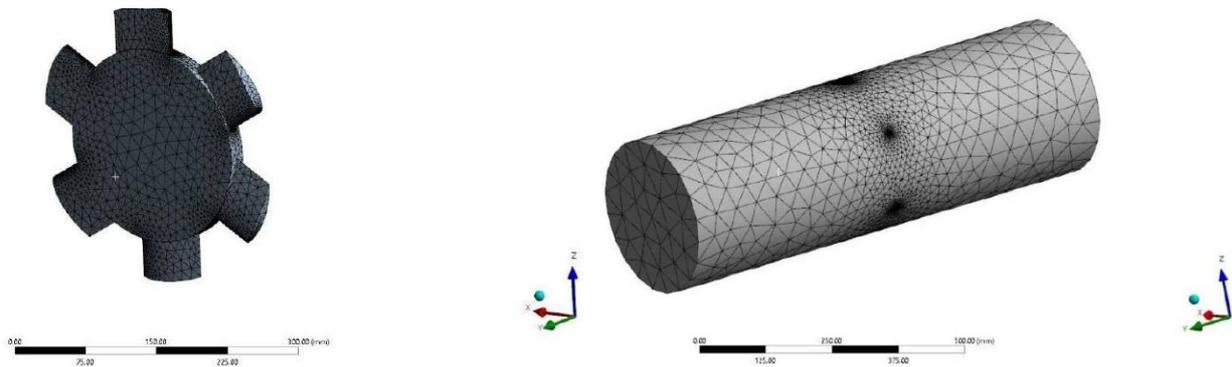


Fig.11. Meshing of Rotor Blade

Names selection of various sides and parts are done and boundary conditions are established for the analysis of the model. In the next step boundary conditions are assigned to the generated mesh and the results are derived for given number of iterations until which the result converges. The convergence graph for the analysis is given as follows:

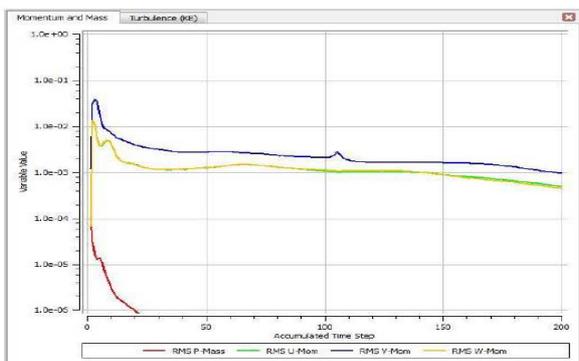


Fig. 12 Convergence graph of turbine with guide vanes

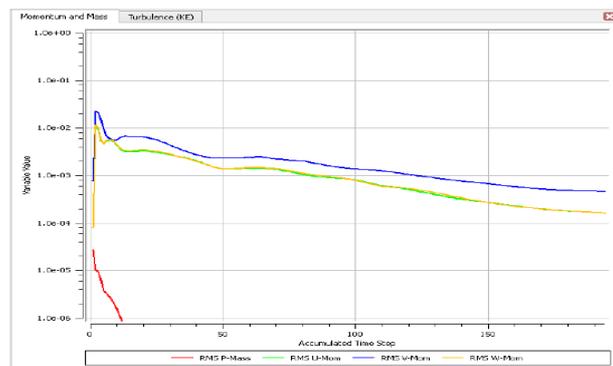


Fig. 13 Convergence graph of turbine without guide vanes

After the solution converged the results for the required velocity and pressure difference is calculated and the graphs for the pressure and velocity profile are generated as follows:

## 1. Turbine without Guide Vanes

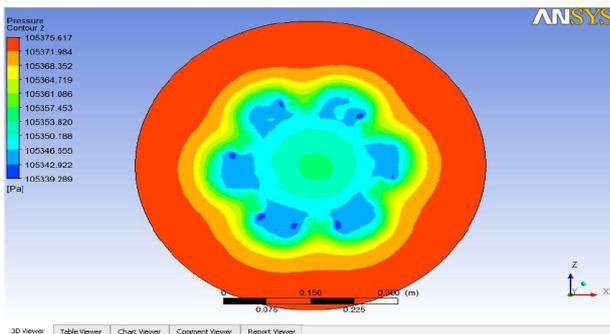


Fig. 13 Pressure variation in the inlet of turbine

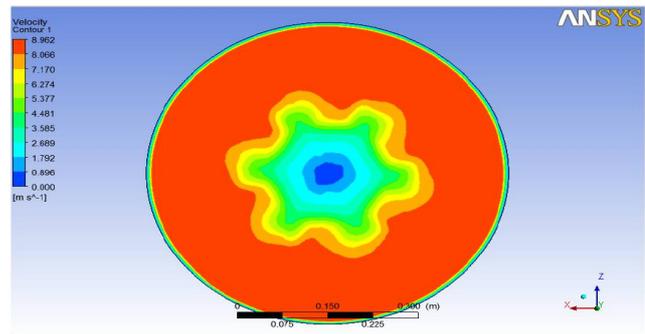


Fig. 14 Velocity variation at the inlet of turbine

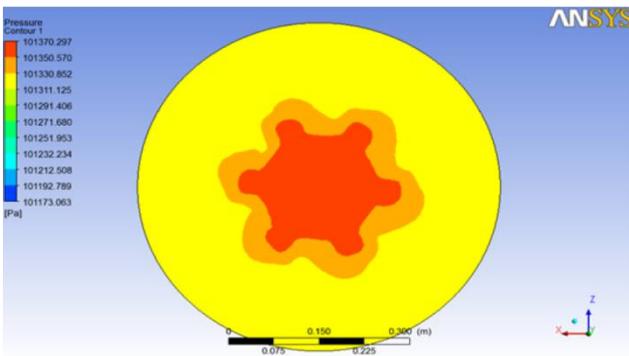


Fig. 15 Pressure variation at the outlet of turbine

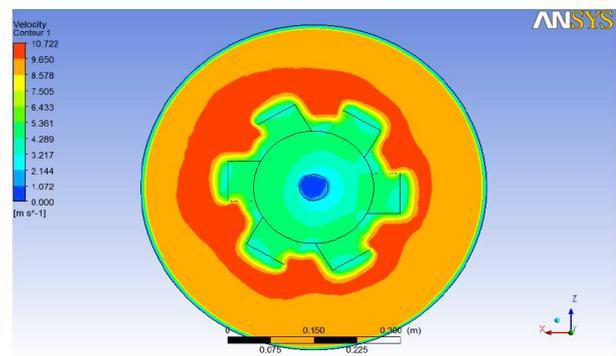


Fig. 15 Velocity variation at the outlet of turbine

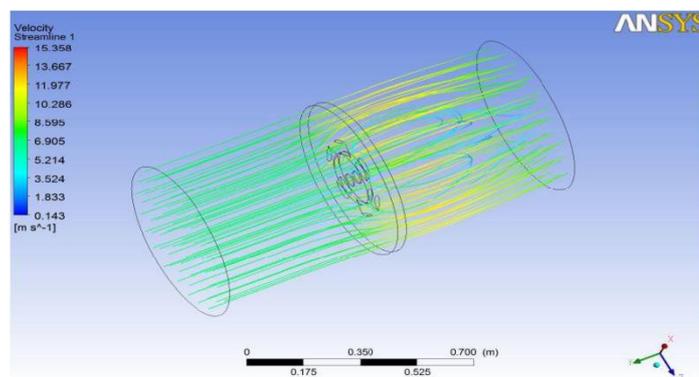


Fig. 16 Velocity Streamlines

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Vol. 7, Issue 1, January 2018

## 2. Turbine with Guide Vanes

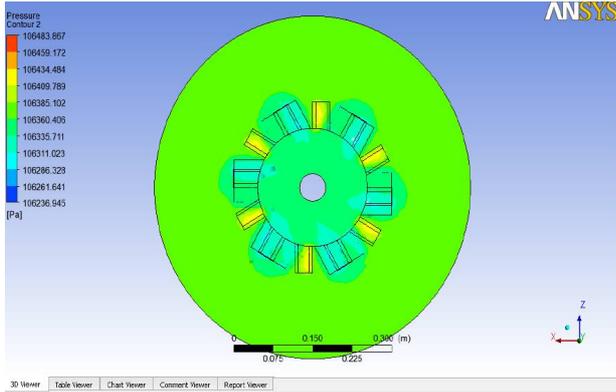


Fig. 17 Pressure variation at the inlet of the guide vanes

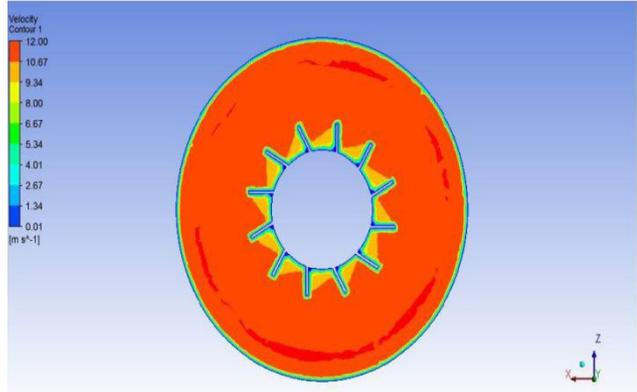


Fig. 18 Velocity variation at the inlet of the guide vanes

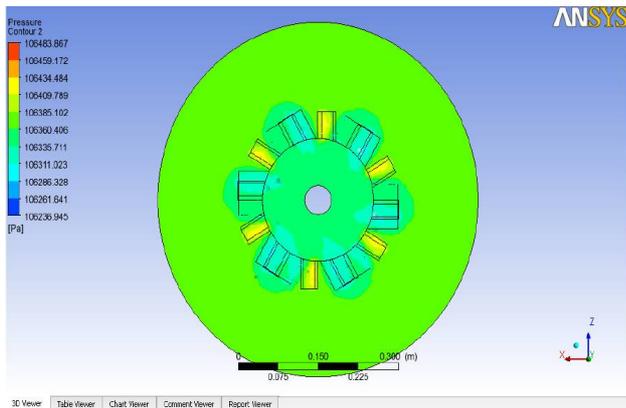


Fig. 19 Pressure variation at the inlet of the Turbine

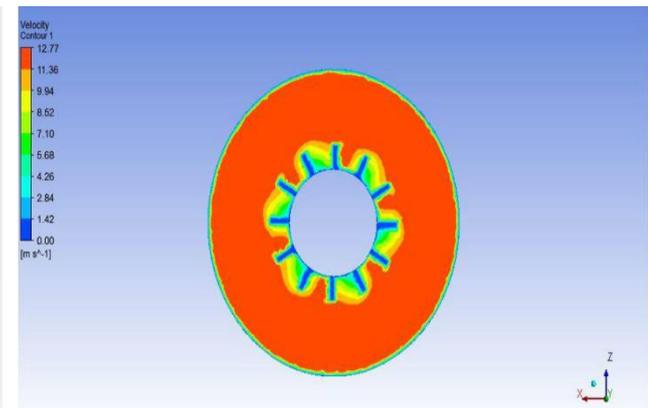


Fig. 20 Velocity variation at the inlet of the Turbine

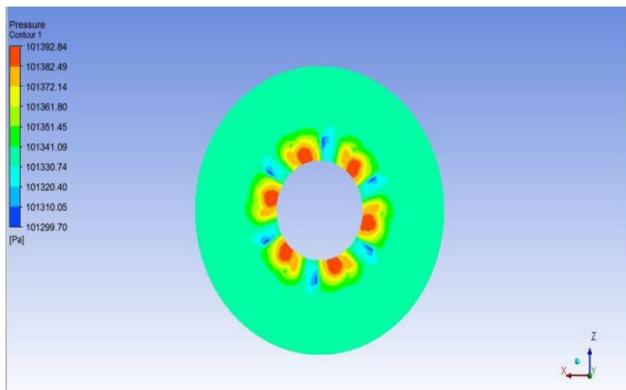


Fig. 21 Pressure variation at the outlet of the Turbine

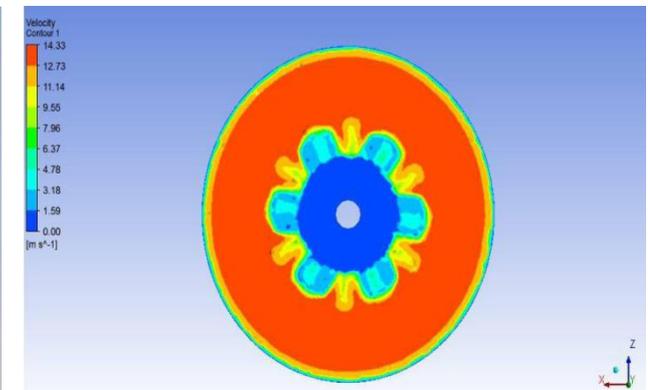


Fig. 22 Velocity variation at the outlet of the Turbine

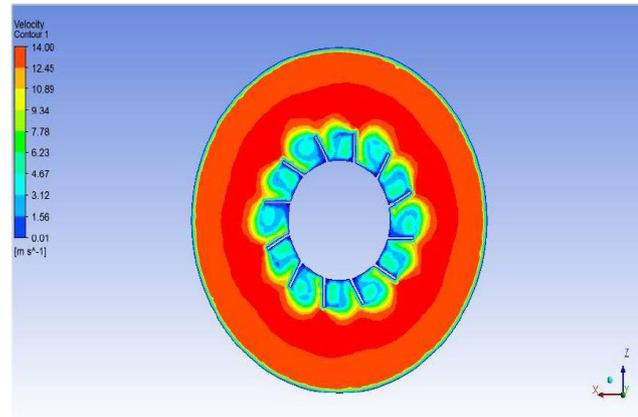
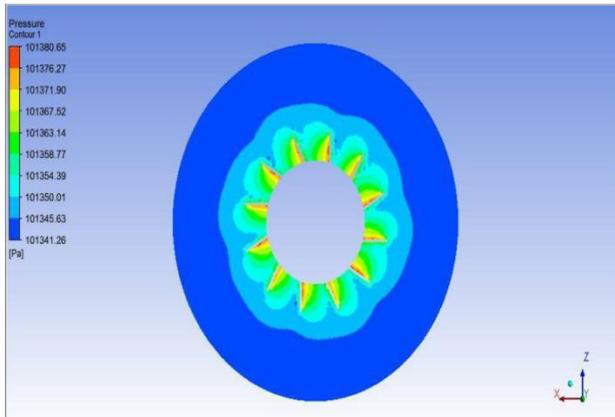


Fig. 23 Pressure variation at the outlet of the Guide vanes

Fig. 24 Velocity variation at the outlet of the Guide Vanes

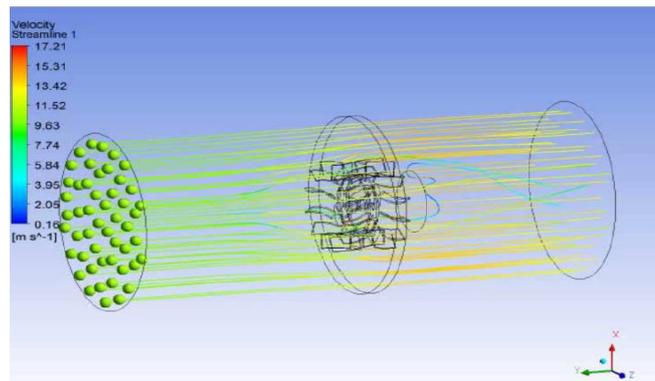


Fig. 24 Velocity Streamlines with Guide Vanes

## VI. CALCULATION OF EFFICIENCY

Formula to be used:-

$$\text{Efficiency, } \eta = \tau \cdot \omega / \Delta p \cdot Q$$

Where  $\tau$  = Torque applied in the blade,

$\omega$  = angular velocity,

$\Delta p$  = pressure difference,

$Q$  = Flow rate.

### 1. CASE 1:- Calculation of efficiency for turbine without guide vanes

$\tau = 5.96 \text{ Nm}$  (derived from numerical analyses)

$I$  (moment of inertia) =  $0.059 \text{ kgm}^2$

Axial Velocity ( $v$ ) =  $8.9 \text{ m/s}$  (derived from numerical analyses)

- $\tau = I\omega$

$$\omega = \tau / I = 5.96 / 0.059 = 101 \text{ rad/s}$$

- $\omega = 2 \cdot \pi \cdot N / 60 =$

$$N = \omega \cdot 60 / 2 \cdot \pi = 101 \times 60 / 2 \times \pi = 964.64 \approx 965 \text{ rpm}$$

- $U$  (circumferential velocity) =  $\pi \cdot d \cdot N / 60$

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Vol. 7, Issue 1, January 2018

$$U = (\pi \times 0.253 \times 965) / 60 = 12.78 \text{ m/s}$$

- **Efficiency,  $\eta = (\tau \cdot \omega) / (\Delta p \cdot Q)$**   
 $Q = A \cdot v = (0.0358) \times (8.9) = 0.3186 \text{ m}^3/\text{s}$   
 $\Delta p = 105370 - 101310 = 4060 \text{ pa}$   
 $\eta = (5.69 \times 101) / (4060 \times 0.3186) = 0.465 = 46.5 \%$

## 2. CASE 2:- Calculation of efficiency for turbine with guide vanes

$\tau = 6.475 \text{ Nm}$  (derived from numerical analyses)

$I$  (moment of inertia) =  $0.059 \text{ kgm}^2$

Axial Velocity ( $v$ ) =  $8.9 \text{ m/s}$  (derived from numerical analyses)

- $\tau = I\omega$   
 $\omega = \tau / I = 6.475 / 0.059 = 110 \text{ rad/s}$
- $\omega = 2\pi N / 60 =$   
 $N = \omega \cdot 60 / 2\pi = 110 \times 60 / 2\pi = 1050.42 \approx 1051 \text{ rpm}$
- **$U$  (circumferential velocity) =  $\pi \cdot d \cdot N / 60$**   
 $U = (\pi \times 0.253 \times 1051) / 60 = 13.92 \text{ m/s}$
- **Efficiency,  $\eta = \tau \cdot \omega / \Delta p \cdot Q$**   
 $Q = A \cdot v = (0.0358) \times (8.9) = 0.3186 \text{ m}^3/\text{s}$   
 $\Delta p = 105360 - 101310 = 4050 \text{ pa}$   
 $\eta = 6.475 \times 110 / 4050 \times 0.3186 = 0.552 = 55.2 \%$

## VII. CONCLUSION

For the turbine without guide vanes the value of torque derived is  $5.96 \text{ Nm}$  whereas for the turbine with guide vanes the value of torque came out to be  $6.475 \text{ Nm}$ , so it seen that there is an increase in the value of torque. This increase in torque directly increases the rpm of the turbine as the mass moment of inertia which is equal to  $0.059 \text{ Kgm}^2$ . The initial rpm was calculated to be  $101 \text{ rad/s}$  which increased to  $110 \text{ rad/s}$  with the application of guide vanes.

From the rpm of rotor the circumferential velocity ( $U$ ) is calculated which comes out to be  $12.78 \text{ m/s}$  for turbine without guide vanes and  $13.92 \text{ m/s}$  for the turbine with guide vanes. This shows the increase in the rotation speed of the turbine. The numerical analysis also provides the pressure difference across the turbine which is equal to  $4060 \text{ pa}$  for the turbine without guide vanes and  $4050 \text{ pa}$  for the turbine with guide vanes.

For a given axial velocity that is  $8.9 \text{ m/s}$  which is found from the numerical analysis, the flow rate that we find is  $0.3186 \text{ m}^3/\text{s}$ . From the above derived values we find that the efficiency of the turbine without the guide vanes is about  $46.5\%$  and that of the turbine with guide vanes gives efficiency of about  $55.2\%$  which gives an approximate of  $8-9\%$  increase in the efficiency of the turbine. Hence we can see that the use of guide vanes can increase the efficiency of the turbine.

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